Technical Standard Order

Subject: TSO-C117, AIRBORNE WINDSHEAR WARNING AND ESCAPE GUIDANCE SYSTEMS FOR TRANSPORT AIRPLANES

(a) Purpose and Scope.

(1) Introduction. This Technical Standard Order (TSO) prescribes the minimum performance standards for airborne windshear warning and escape guidance systems for transport category airplanes. This document defines performance, functions, and features for systems providing windshear warning and escape guidance commands based upon sensing the airplane's encounter of such phenomena. It is not applicable to systems that look ahead to sense windshear conditions before the phenomenon is encountered nor to systems that use atmospheric and/or other data to predict the likelihood of a windshear alert. Airborne windshear warning and escape guidance systems that are to be identified with TSO identification and that are manufactured on or after the date of this TSO must meet the minimum performance standard specified herein.

(2) Scope. This TSO applies only to windshear warning systems which identify windshear phenomenon by sensing the encounter of conditions exceeding the threshold values contained in this TSO. In addition to windshear warning criteria, this TSO provides criteria applicable to systems that provide optional windshear caution alert capability. Windshear escape guidance is provided to assist the pilot in obtaining the desired flight path during such an encounter.

(3) Applicable Documents. The following documents shall form a part of this TSO to the extent specified herein. Should conflicting requirements exist, the contents of this TSO shall be followed.

(i) Radio Technical Commission for Aeronautics (RTCA) Document No. DO-160B, "Environmental Conditions and Test Procedures for Airborne Equipment," dated July 1984.

(ii) RTCA Document No. DO-178A, "Software Considerations in Airborne Systems and Equipment Certification," dated March 1985.

of windshear once the phenomena is encountered and provides the pilot with timely warning. The system may include both windshear warning and windshear caution alerts. A warning device of this type does not provide escape guidance information to the pilot to satisfy the criteria for warning and flight guidance systems.

(ii) Airborne Windshear Warning and Escape Guidance System. A device or system which uses various sensor inputs to identify the presence of windshear once the phenomenon is encountered and provides the pilot with timely warning and adequate flight guidance to improve the probability of recovery from the windshear encounter. This system may include both windshear warning and windshear caution alerts.

(iii) Airborne Windshear Auto Recovery System. A device or system which integrates or couples autopilot and/or autothrottle systems of the aircraft with an airborne windshear flight guidance system.

(iv) Airborne Windshear Escape Guidance System. A system which provides the crew with flight guidance information to improve the recovery probability once encountering a windshear phenomenon.

(v) Failure. The inability of a system, subsystem, unit, or part to perform within previously specified limits.

(vi) False Warning or Caution. A warning or caution which occurs when the design windshear warning or caution threshold of the system is not exceeded.

(vii) Nuisance Warning or Caution. A warning or caution which occurs when a phenomenon is encountered, such as turbulence, which does not, in fact, endanger the aircraft because of the duration or subsequent change of the windshear magnitude.

(viii) Recovery Procedure. A vertical flight path control technique used to maximize recovery potential from an inadvertent encounter with windshear.

increasing performance conditions which is set at a windshear level requiring immediate crew awareness and likely subsequent corrective action.

(xi) Windshear Warning Alert. An alert triggered by decreasing performance conditions which is set at a windshear level requiring immediate corrective action by the pilot.

(b) General Standards. The following general requirements shall be met by all windshear warning and escape guidance systems:

(1) Airworthiness. Design and manufacture of the airborne equipment must provide for installation so as not to impair the airworthiness of the aircraft. Material shall be of a quality which experience and/or tests have demonstrated to be suitable and dependable for use in aircraft systems. Workmanship shall be consistent with high quality aircraft electromechanical and electronic component manufacturing practices.

(2) General Performance. The equipment must perform its intended function, as defined by the manufacturer.

(3) Fire Resistance. Except for small parts (such as knobs, fasteners, seals, grommets, and small electrical parts) that would not significantly contribute to the propagation of fire, all materials used must be self-extinguishing. One means for showing compliance with this requirement is contained in Federal Aviation Regulations (FAR) Part 25, Appendix F.

(4) Operation of Controls. Controls intended for use during flight shall be designed to minimize errors, and when operated in all possible combinations and sequences, shall not result in a condition whose presence or continuation would be detrimental to the continued performance of the equipment.

(5) Accessibility of Controls. Controls that are not normally adjusted in flight shall not be readily accessible to the operator.

(6) Interfaces. The interfaces with other aircraft equipment must be designed such that normal or abnormal windshear warning and escape guidance equipment operation shall not adversely affect the operation of other equipment.

identified with the same manufactured part number shall be completely interchangeable.

(9) Control/Display Capability. A suitable interface shall be provided to allow data input, data output, and control of equipment operation. The control/display shall be operable by one person with the use of only one hand.

(10) Control/Display Readability. The equipment shall be designed so that all displays and controls shall be readable under all cockpit ambient light conditions ranging from total darkness to reflected sunlight and arranged to facilitate equipment usage. Limitations on equipment installations to ensure display readability should be included in the installation instructions.

(11) Effects of Test. The design of the equipment shall be such that the application of the specified test procedures shall not produce a condition detrimental to the performance of the equipment except as specifically allowed.

(12) Equipment Computational Response Time. The equipment shall employ suitable update rates for computation and display of detection and guidance information.

(13) Supplemental Heating or Cooling. If supplemental heating or cooling is required by system components to ensure that the requirements of this TSO are met, they shall be specified by the equipment manufacturer in the installation instructions.

(14) Self-Test Capability. The equipment shall employ a self-test capability to verify proper system operation.

(i) Any manually initiated self-test mode of operation shall automatically return the system to the normal operating mode upon completion of a successful test.

(ii) Any automatically activated self-test feature must annunciate this mode of operation to the pilot if this feature activates annunciation lights, aural messages, or displaces the guidance commands in any way.

(iii) Conduct of the system self-test feature must not adversely affect the performance or operation of other aircraft systems.

the presentation of information from the other. A warning system failure shall not result in ambiguous or erroneous guidance system mode annunciation.

(16) System Reliability.

(i) The probability of a false warning being generated within the windshear warning system or the windshear warning and escape guidance system shall be 1×10^{-4} or less per flight hour.

(ii) The probability of an unannunciated failure of the windshear warning system or the windshear warning and escape guidance system shall be 1×10^{-5} or less per flight hour (1×10^{-3} or less per flight hour for systems installed in out of production aircraft as defined in FAR 121.358).

(c) Equipment Functional Requirements - Standard Conditions. The equipment shall meet the following functional requirements.

(1) Mode Annunciation. The windshear escape guidance display mode of operation shall be annunciated to the pilot upon escape guidance activation during a windshear encounter and upon reversion to a different flight guidance mode.

(2) Malfunction/Failure Indications. The equipment shall indicate:

(i) Inadequate or absence of primary power.

(ii) Equipment failures.

(iii) Inadequate or invalid warning or guidance displays or output signals.

(iv) Inadequate or invalid sensor signals or sources.

These malfunction/failure indications shall occur independently of any operator action. The lack of adequate warning displays, escape guidance information, or sensor signals or sources shall be annunciated when compliance with the requirements of this TSO cannot be assured.

(ii) This caution alert shall display or provide an appropriate output for display of an amber caution annunciation dedicated for this purpose. An aural alert may be provided as an option. The caution display (or output) should remain until the threshold windshear condition no longer exists (not less than a minimum of 3 seconds) or a windshear warning alert occurs.

(iii) Gust conditions shall not cause a nuisance caution alert. Turbulence shall not cause more than one nuisance caution alert per 250 hours (or 3,000 flight cycles based on 1 hour/flight cycle) of system operation.

(4) Windshear Warning Alert.

(i) A windshear warning alert shall provide an annunciation of decreasing performance shear (downdraft, decreasing headwind, or increasing tailwind) with a magnitude equal or greater than that shown in the shear intensity curve shown in figure 1.

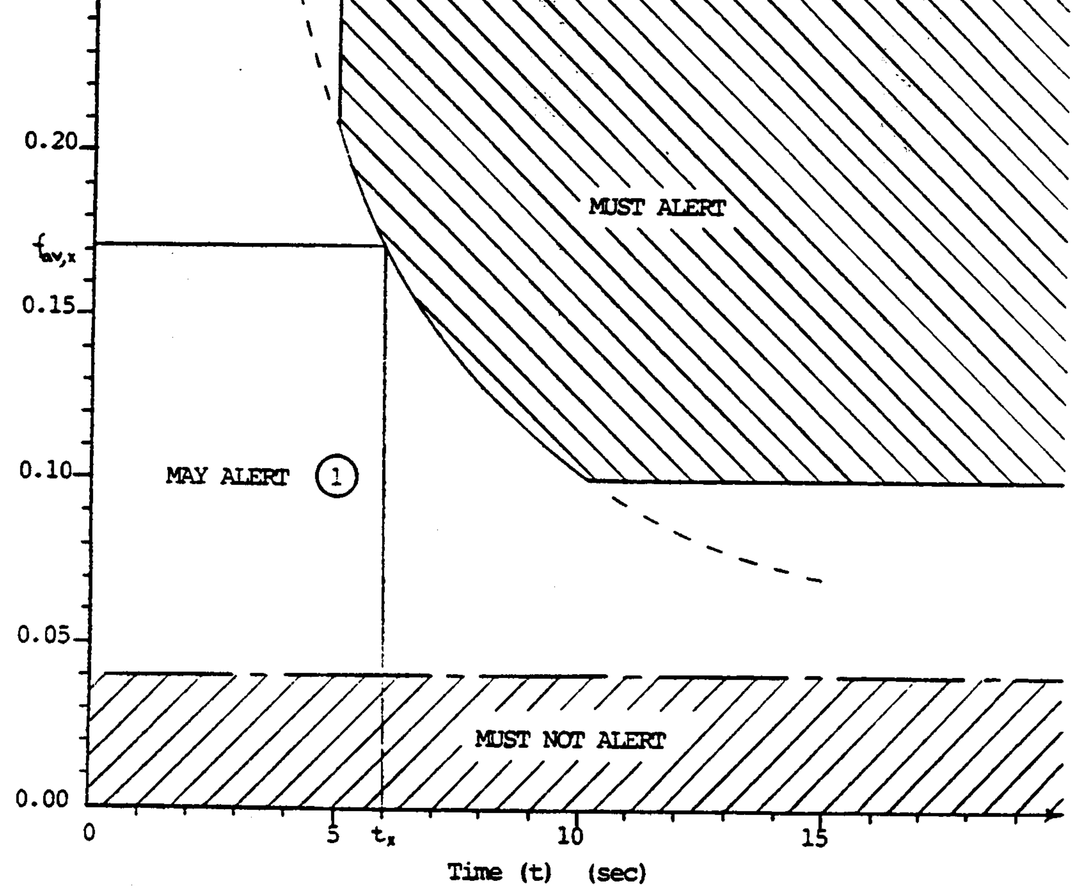
(ii) This warning alert shall display or provide an appropriate output for display of an red warning annunciation labeled "windshear" dedicated for this purpose. The visual alert should remain at least until the threshold windshear condition no longer exists or a minimum of 3 seconds, whichever is greater. An aural alert shall be provided that annunciates "windshear" for three aural cycles. The aural alert need not be repeated for subsequent windshear warning alerts within the same mode of operation.

(iii) Gust conditions shall not cause a nuisance warning alert. Turbulence shall not cause more than one nuisance warning alert per 250 hours (or 3,000 flight cycles based on 1 hour/flight) of system operation.

(5) Operating Altitude Range. The system shall be designed to function from at least 50 feet above ground level (AGL) to at least 1000 feet AGL.

(6) Windshear Escape Guidance. Flight guidance algorithms shall incorporate the following design considerations:

(i) At the point of system warning threshold, the available energy of the airplane must be properly managed through a representative number of windfield conditions. These conditions



$f_{av,x}$ = average shear intensity to cause a warning at time t_x (resulting in a 20 knot windspeed change, bounded as shown; applies to horizontal, vertical, and combination shear intensities)

$$= \frac{\int_0^{t_x} f(t)dt}{t_x}$$ whereby $f(t)$ = instantaneous shear intensity at time t

(1) A nuisance warning test utilizing the Dryden turbulence model and a discrete gust model are conducted independently from alert threshold tests to verify the acceptability of potential nuisance warnings due to turbulence or gusts.

such as to overcome the performance capability of the airplane, guidance commands must be such that ground impact will occur in the absence of ability to produce additional lift, absence of excessive kinetic energy, and without putting the aircraft into a stalled condition.

(iv) Flight guidance command information shall be provided for presentation on the primary flight display/attitude direction indicator (PFD/ADI) and any available Head Up Display (HUD).

(v) Flight guidance displays which command flight path and pitch attitude should be limited to an angle-of-attack equivalent to onset of stall warning or a maximum pitch command of 27°, whichever is less.

(vi) Flight guidance commands and any auto recovery mode (if included) may be automatically activated concurrent with or after the windshear warning alert occurs or may be manually selected. If manual selection is utilized, it shall only be via the takeoff-go around (TOGA) switch or equivalent means (i.e., a function of throttle position, other engine parameters, etc.).

(vii) Manual deselection of windshear flight guidance and any auto recovery mode (if included) shall be possible by means other than the TOGA switches.

(viii) Systems incorporating automatic reversion of flight guidance commands from windshear escape guidance to another flight guidance mode should provide a smooth transition between modes. Flight guidance commands shall not be removed from the flight guidance display until either manually deselected or until the aircraft, following exit of the warning conditions, has maintained a positive rate of climb and speed above 1.3 V_{s1} for at least 30 seconds.

(d) <u>Equipment Performance - Environmental Conditions</u>. The environmental tests and performance requirements described in this subsection are intended to provide a laboratory means of determining the overall performance characteristics of the equipment under conditions representative of those that may be encountered in actual operations. Some of the environmental tests contained in this subsection need not be performed unless the manufacturer wishes to qualify the equipment for that particular

Conditions and Test Procedures for Airborne Equipment." Performance tests which must be made after subjection to test environments may be conducted after exposure to several environmental conditions.

(1) Temperature and Altitude Tests (DO-160B, Section 4.0). RTCA Document DO-160B contains several temperature and altitude test procedures which are specified according to the category for which the equipment will be used. These categories are included in paragraph 4.2 of DO-160B. The following subsections contain the applicable test conditions specified in Section 4.0 of DO-160B.

(i) Low Operating Temperature Test. The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 4.5.1, and the following requirements of this standard shall be met:

(a) Section (c)(1) - Mode Annunciation
(b) Section (c)(2) - Malfunction/Failure Indications
(c) Section (c)(3) - Windshear Caution Alert
(d) Section (c)(4) - Windshear Warning Alert
(e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(ii) High Short-Time Operating Temperature Test. The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 4.5.2, and the following requirements of this standard shall be met:

(a) Section (c)(1) - Mode Annunciation
(b) Section (c)(2) - Malfunction/Failure Indications
(c) Section (c)(3) - Windshear Caution Alert
(d) Section (c)(4) - Windshear Warning Alert
(e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(c) Section (c)(3) - Windshear Caution Alert
(d) Section (c)(4) - Windshear Warning Alert
(e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(iv) In-Flight Loss of Cooling Test (When Required). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 4.5.4, and the following requirements of this standard shall be met:

(a) Section (c)(1) - Mode Annunciation
(b) Section (c)(2) - Malfunction/Failure Indications
(c) Section (c)(3) - Windshear Caution Alert
(d) Section (c)(4) - Windshear Warning Alert
(e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(v) Altitude Test. The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 4.6.1, and the following requirements of this standard shall be met:

(a) Section (c)(1) - Mode Annunciation
(b) Section (c)(2) - Malfunction/Failure Indications
(c) Section (c)(3) - Windshear Caution Alert
(d) Section (c)(4) - Windshear Warning Alert
(e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(vi) Decompression Test (When Required). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 4.6.2, and the following requirements of this standard shall be met:

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(vii) Overpressure Test (When Required). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 4.6.3, and the following requirements of this standard shall be met:

(a) Section (c)(1) - Mode Annunciation
(b) Section (c)(2) - Malfunction/Failure Indications
(c) Section (c)(3) - Windshear Caution Alert
(d) Section (c)(4) - Windshear Warning Alert
(e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(2) Temperature Variation Test (DO-160B, Section 5.0). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, Section 5.0, and the following requirements of this standard shall be met:

(i) Section (c)(1) - Mode Annunciation
(ii) Section (c)(2) - Malfunction/Failure Indications
(iii) Section (c)(3) - Windshear Caution Alert
(iv) Section (c)(4) - Windshear Warning Alert
(v) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(3) Humidity Test (DO-160B, Section 6.0). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, Section 6.0, and the following requirements of this standard shall be met:

(i) Section (c)(1) - Mode Annunciation
(ii) Section (c)(2) - Malfunction/Failure Indications
(iii) Section (c)(3) - Windshear Caution Alert
(iv) Section (c)(4) - Windshear Warning Alert

subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 7.2, and the following requirements of this standard shall be met:

(a) Section (c)(1) - Mode Annunciation
(b) Section (c)(2) - Malfunction/Failure Indications
(c) Section (c)(3) - Windshear Caution Alert
(d) Section (c)(4) - Windshear Warning Alert
(e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(ii) Crash Safety Shocks. The application of the crash safety shock tests may result in damage to the equipment under test. Therefore, this test may be conducted after the other tests have been completed. In this case, section (b)(11), "Effects of Test," of this standard does not apply. The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 7.3, and shall meet the requirements specified therein.

(5) Vibration Test (DO-160B, Section 8.0). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160 , Section 8.0, and the following requirements of this standard shall be met:

(i) Section (c)(1) - Mode Annunciation
(ii) Section (c)(2) - Malfunction/Failure Indications
(iii) Section (c)(3) - Windshear Caution Alert
(iv) Section (c)(4) - Windshear Warning Alert
(v) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(6) Explosion Proofness Test (DO-160B, Section 9.0) (When Required). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, Section 9.0. During these tests, the equipment shall not cause detonation of the explosive mixture within the test chamber.

(b) Section (c)(2) - Malfunction/Failure Indications

(c) Section (c)(3) - Windshear Caution Alert

(d) Section (c)(4) - Windshear Warning Alert

(e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs and outputs shall perform their intended functions.

(ii) Spray Proof Test (When Required). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 10.3.2, and the following requirements of this standard shall be met:

NOTE: This test shall be conducted with the spray directed perpendicular to the most vulnerable area(s) as determined by the equipment manufacturer.

(a) Section (c)(1) - Mode Annunciation

(b) Section (c)(2) - Malfunction/Failure Indications

(c) Section (c)(3) - Windshear Caution Alert

(d) Section (c)(4) - Windshear Warning Alert

(e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(iii) Continuous Stream Proof Test (When Required). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 10.3.3, and the following requirements of this standard shall be met:

(a) Section (c)(1) - Mode Annunciation

(b) Section (c)(2) - Malfunction/Failure Indications

(c) Section (c)(3) - Windshear Caution Alert

(d) Section (c)(4) - Windshear Warning Alert

(e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

At the end of the 24-hour exposure period, the equipment shall operate at a level of performance that indicates that no significant failures of components or circuitry have occurred. Following the two-hour operational period at ambient temperature, after the 160-hour exposure period at elevated temperature, the following requirements of this standard shall be met:

(a) Section (c)(1) - Mode Annunciation
(b) Section (c)(2) - Malfunction/Failure Indications
(c) Section (c)(3) - Windshear Caution Alert
(d) Section (c)(4) - Windshear Warning Alert
(e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(ii) Immersion Test (When Required). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 11.4.2, and the following requirements of this standard shall be met:

At the end of the 24-hour immersion period specified in DO-160B, paragraph 11.4.2, the equipment shall operate at a level of performance that indicates that no significant failures of components or circuitry have occurred. Following the two-hour operational period at ambient temperature, after the 160-hour exposure period at elevated temperature, the following requirements of this standard shall be met:

(a) Section (c)(1) - Mode Annunciation
(b) Section (c)(2) - Malfunction/Failure Indications
(c) Section (c)(3) - Windshear Caution Alert
(d) Section (c)(4) - Windshear Warning Alert
(e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(9) Sand and Dust Test (DO-160B, Section 12.0) (When Required). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, Section 12.0, and the following requirements of this standard shall be met:

inputs, and outputs shall perform their intended functions.

(10) <u>Fungus Resistance Test (DO-160B, Section 13.0) (When Required)</u>. The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, Section 13.0, and the following requirements of this standard shall be met:

(i) Section (c)(1) - Mode Annunciation
(ii) Section (c)(2) - Malfunction/Failure Indications
(iii) Section (c)(3) - Windshear Caution Alert
(iv) Section (c)(4) - Windshear Warning Alert
(v) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(11) <u>Salt Spray Test (DO-160B, Section 14.0) (When Required)</u>. The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, Section 14.0, and the following requirements of this standard shall be met:

(i) Section (c)(1) - Mode Annunciation
(ii) Section (c)(2) - Malfunction/Failure Indications
(iii) Section (c)(3) - Windshear Caution Alert
(iv) Section (c)(4) - Windshear Warning Alert
(v) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs and outputs shall perform their intended functions.

(12) <u>Magnetic Effect Test (DO-160B, Section 15.0)</u>. The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, Section 15.0, and the equipment shall meet the requirements of the appropriate instrument or equipment class specified therein.

(13) <u>Power Input Tests (DO-160B, Section 16.0)</u>.

(i) <u>Normal Operating Conditions</u>. The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraphs 16.5.1 and 16.5.2, as appropriate, and the following requirements of this standard shall be met:

and outputs shall perform their intended functions.

(ii) Abnormal Operating Conditions. The application of the low voltage conditions (DC) (Category B equipment) test may result in damage to the equipment under test. Therefore, this test may be conducted after the other tests have been completed. Section (b)(11), "Effects of Test," does not apply. The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraphs 16.5.3 and 16.5.4, as appropriate, and the following requirements of this standard shall be met:

(a) Section (c)(1) - Mode Annunciation
(b) Section (c)(2) - Malfunction/Failure Indications
(c) Section (c)(3) - Windshear Caution Alert
(d) Section (c)(4) - Windshear Warning Alert
(e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(14) Voltage Spike Conducted Test (DO-160B, Section 17.0).

(i) Category A Requirements (If Applicable). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 17.3, and the following requirements of this standard shall be met:

(a) Section (c)(1) - Mode Annunciation
(b) Section (c)(2) - Malfunction/Failure Indications
(c) Section (c)(3) - Windshear Caution Alert
(d) Section (c)(4) - Windshear Warning Alert
(e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs and outputs shall perform their intended functions.

(ii) Category B Requirements (If Applicable). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraphs 17.4.1 and 17.4.2, and the following requirements of this standard shall be met:

and outputs shall perform their intended functions.

(15) <u>Audio Frequency Conducted Susceptibility Test (DO-160B, Section 18.0)</u>. The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, Section 18.0, and the following requirements of this standard shall be met:

(i) Section (c)(1) - Mode Annunciation
(ii) Section (c)(2) - Malfunction/Failure Indications
(iii) Section (c)(3) - Windshear Caution Alert
(iv) Section (c)(4) - Windshear Warning Alert
(v) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(16) <u>Induced Signal Susceptibility Test (DO-160B, Section 19.0)</u>. The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, Section 19.0, and the following requirements of this standard shall be met:

(i) Section (c)(1) - Mode Annunciation
(ii) Section (c)(2) - Malfunction/Failure Indications
(iii) Section (c)(3) - Windshear Caution Alert
(iv) Section (c)(4) - Windshear Warning Alert
(v) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs and outputs shall perform their intended functions.

(17) <u>Radio Frequency Susceptibility Test (Radiated and Conducted) (DO-160B, Section 20.0)</u>. The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, Section 20.0, and the following requirements of this standard shall be met:

(i) Section (c)(1) - Mode Annunciation
(ii) Section (c)(2) - Malfunction/Failure Indications
(iii) Section (c)(3) - Windshear Caution Alert

conditions as specified in RTCA Document DO-160B, Section 21.0, and the requirements specified therein shall be met.

(19) Lightning Induced Transient Susceptibility (DO-160B, Section 22.0). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, Section 22.0, and the requirements specified therein shall be met:

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(e) Equipment Test Procedures.

(1) Definitions of Terms and Conditions of Tests. The following definitions of terms and conditions of tests are applicable to the equipment tests specified herein:

(i) Power Input Voltage. Unless otherwise specified, all tests shall be conducted with the power input voltage adjusted to design voltage ± 2 percent. The input voltage shall be measured at the input terminals of the equipment under test.

(ii) Power Input Frequency.

(a) In the case of equipment designed for operation from an AC power source of essentially constant frequency (e.g., 400 Hz), the input frequency shall be adjusted to design frequency ± 2 percent.

(b) In the case of equipment designed for operation from an AC power source of variable frequency (e.g., 300 to 1000 Hz), unless otherwise specified, tests shall be conducted with the input frequency adjusted to within 5 percent of a selected frequency and within the range for which the equipment is designed.

(iii) Windfield Models. Unless otherwise specified, the windfield models used for tests shall be those specified in appendix 1 of this TSO.

(iv) Adjustment of Equipment. The circuits of the equipment under test shall be aligned and adjusted in accordance input and output impedances of the equipment under test.

(vi) Ambient Conditions. Unless otherwise specified, all tests shall be conducted under conditions of ambient room temperature, pressure,and humidity. However, the room temperature shall be not lower than 10° C.

(vii) Warm-up Period. Unless otherwise specified, all tests shall be conducted after the manufacturer's specified warm-up period.

(viii) Connected Loads. Unless otherwise specified, all tests shall be performed with the equipment connected to loads which have the impedance values for which it is designed.

(2) Test Procedures. The equipment shall be tested in all modes of operation that allow different combinations of sensor inputs to show that it meets both functional and accuracy criteria.

Dynamic testing provides quantitative data regarding windshear warning and escape guidance equipment performance using a simplified simulation of flight conditions. This testing, when properly performed and documented, may serve to minimize the flight test requirements.

It shall be the responsibility of the equipment manufacturer to determine that the sensor inputs, when presented to the windshear warning and escape guidance equipment, will produce performance commensurate with the requirements of this standard. Additional sensor inputs may be optionally provided to enhance equipment capability and/or performance.

The equipment required to perform these tests shall be defined by the equipment manufacturer as a function of the specific sensor configuration of his equipment. Since these tests may be accomplished more than one way, alternative test equipment setups may be used where equivalent test function can be accomplished. Combinations of tests may be used wherever appropriate.

The test equipment signal sources shall provide the appropriate signal format for input to the specific system under test without contributing to the error values being measured. Tests need only be done once unless otherwise indicated.

(3) Test Setup. Simulator tests shall be used to demonstrate the performance capability of the windshear warning and escape guidance equipment. A suitable equipment interface shall be provided for recording relevant parameters necessary to evaluate the particular system under test. The aircraft simulator shall be capable of appropriate dynamic modeling of a representative aircraft and of the windfield and turbulence conditions contained in appendices 1 and 2 of this TSO or other windfield/turbulence models found acceptable by the Administrator.

(4) Functional Performance (paragraphs (c)(1) through (c)(6)). Each of the functional capabilities identified in paragraphs (c)(1) through (c)(6) shall be demonstrated with the windshear warning and escape guidance equipment powered. These capabilities shall be evaluated either by inspection or in conjunction with the tests described in paragraphs (e)(5) through (e)(11).

(5) Mode Annunciation (paragraph (c)(1)). With the equipment operating, verify the windshear escape guidance display mode of operation is annunciated to the pilot upon escape guidance activation and upon reversion to a different flight guidance mode.

(6) Malfunction/Failure Indications (paragraph (c)(2)). Configure the equipment for simulation tests as defined in paragraph (e)(3).

(i) With the system active (within the operating altitude range) and inactive (outside the operating altitude range), remove one at a time each required electrical power input to the equipment. There shall be a failure indication by the equipment of each simulated failure condition.

(ii) With the system active (within the operating altitude range) and inactive (outside the operating altitude range), cause each sensor or other signal input to become inadequate or invalid. There shall be a failure indication by the equipment of each simulated failure condition.

(7) Windshear Caution Alert (paragraph (c)(3)). For equipment incorporating a windshear caution alert function, accomplish the following tests:

$f_{av,x}$ (1)	Time of Exposure (t) (sec)	Result
0.02	20	no alert
0.04	20	no alert
0.105	10	alert within 10 sec
1.049/t	t	alert within t sec (2)
0.21	5	alert within 5 sec
≥0.270	5	alert within 5 sec

Notes: (1) The average shear intensity which must result in a caution alert after a time t_x or less meets the definition of $f_{av,x}$ in figure 1. The maximum instantaneous shear intensity of the test waveform is restricted to 0.075 or 100 percent of $f_{av,x}$ above the average shear value $f_{av,x}$, whichever is less. The minimum instantaneous shear intensity of the test waveform is zero. Test waveform rise and fall rates shall be limited to a maximum of 0.1 per second. The shear intensity before time 0 is zero for a sufficiently long time to allow the system to settle to stable conditions.

(2) t = 6, 7, 8, 9

The test conditions specified above shall be repeated 5 times. A different waveform for $f_{av,x}$ will be utilized for each of the 5 runs. An appropriate alert (or no alert) must be generated for each test condition.

Verify the system displays or provides an appropriate output for display of an amber caution annunciation dedicated for this purpose. Verify the visual caution display (or output) remains at least until the threshold windshear condition no longer exists or a minimum of 3 seconds (whichever is greater), or until a windshear warning occurs.

(ii) Subject the equipment to windspeeds defined by the Dryden turbulence model contained in appendix 2. The system shall be exposed to these conditions for a minimum of 50 hours (or 600 flight cycles) at each altitude specified in appendix 2 for a minimum total test duration of 250 hours (or 3,000 flight cycles based on 1 hour/flight cycle). No more than one nuisance caution shall be generated during this test.

acceleration waveform values meeting the following conditions (reference figure 2). The system shall generate an appropriate warning alert (or no alert) within the time intervals specified when subjected to the following average shear intensity ($f_{av,x}$) values:

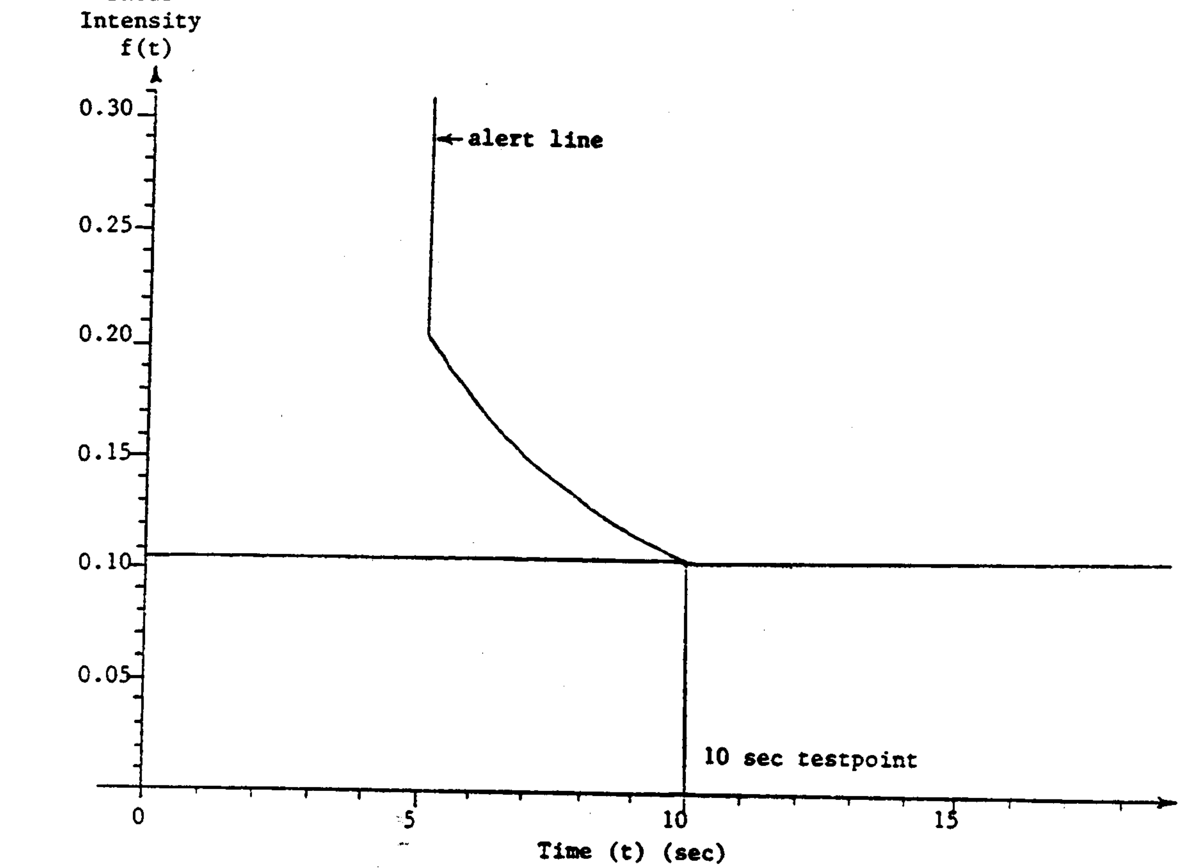
$f_{av,x}$ (1)	Time of Exposure (t) (sec)	Result
0.02	20	no alert
0.04	20	no alert
0.105	10	alert within 10 sec
1.049/t	t	alert within t sec (2)
0.21	5	alert within 5 sec
≥0.270	5	alert within 5 sec

Notes: (1) The average shear intensity which must result in a warning alert after a time t_x or less meets the definition of $f_{av,x}$ in figure 1. The maximum instantaneous shear intensity of the test waveform is restricted to 0.075 or 100 percent of $f_{av,x}$ above the average shear value $f_{av,x}$, whichever is less. The minimum instantaneous shear intensity of the test waveform is zero. Test waveform rise and fall rates shall be limited to a maximum of 0.1 per second. The shear intensity before time 0 is zero for a sufficiently long time to allow the system settle to stable conditions.

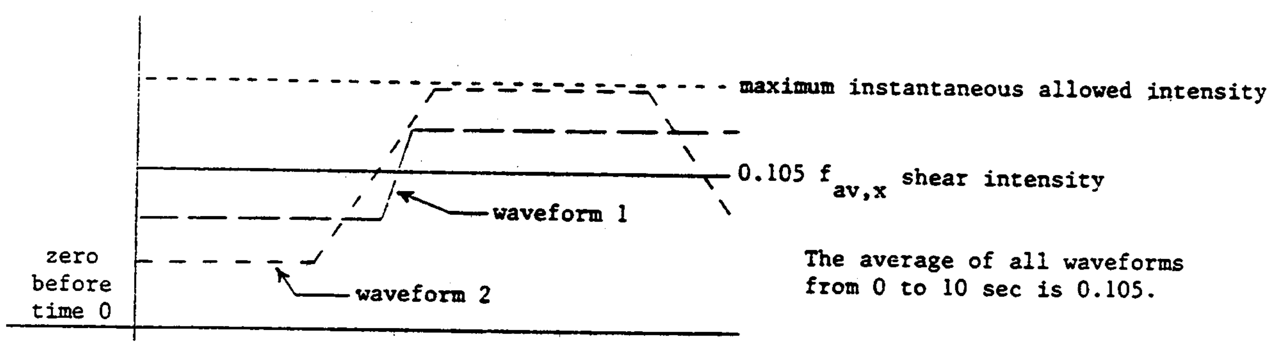
(2) t = 6, 7, 8, 9

The test conditions specified above shall be repeated 5 times. A different waveform for $f_{av,x}$ will be utilized for each of the 5 runs. An appropriate alert (or no alert) must be generated for each test condition.

Verify the system displays or provides an appropriate output for display of a red warning annunciation labeled "windshear" dedicated for this purpose. Verify the visual warning display (or output) remains until the threshold windshear condition no longer exists or a minimum of 3 seconds, whichever is greater. Verify an aural alert is provided that annunciates "windshear" for three aural cycles.



Sample waveforms for 10 sec test point



(iii) Subject the equipment to windspeeds defined by the discrete gust rejection model contained in appendix 2. No alert shall be generated as a result of this test.

(9) Operating Altitude Range (paragraph (c)(5)). Configure the equipment for simulation tests as defined in paragraph (e)(3). Simulate a takeoff to an altitude of at least 1500 feet AGL. Verify the windshear warning and escape guidance system is operational from at least 50 feet AGL to at least 1000 feet AGL. Simulate an approach to landing from 1500 feet AGL to touchdown. Verify the windshear warning and escape guidance system is operational from at least 1000 feet AGL to at least 50 feet AGL.

(10) Windshear Escape Guidance (paragraph (c)(6)). Configure the equipment for simulation tests as defined in paragraph (e)(3). Subject the equipment to each of the windfield conditions contained in appendix 1 for each operating mode (takeoff, approach, landing, etc.) available. Each test condition shall be repeated 5 times. Recovery actions for the fixed pitch method comparison shall be initiated immediately upon entering the shear condition.

(i) Verify the flight path guidance commands manage the available energy of the aircraft to achieve the desired trajectory through the shear encounter. These tests shall be performed with vertical only, horizontal only, and combination vertical and horizontal shear conditions.

(a) For the takeoff case, verify the flight guidance commands produce a trajectory that provides a resultant flight path at least as good (when considered over the entire spectrum of test cases) as that obtained by establishing a 15° pitch attitude (at an approximate rate of 1.5° per second) until onset of stall warning and then reducing pitch attitude to remain at the onset of stall warning until exiting the shear condition. Evidence of a significant decrement (considered over the entire spectrum of test cases) below the flight path provided by the fixed pitch method that results from use of the guidance commands provided by the system must be adequately substantiated.

significant decrement (considered over the entire spectrum of test cases) below the flight path provided by the fixed pitch method that results from use of the guidance commands provided by the system must be adequately substantiated.

(c) For shear conditions exceeding the available performance capability of the aircraft, verify the flight guidance commands result in ground impact in the absence of ability to produce additional lift, absence of excessive kinetic energy, and without putting the aircraft into a stalled condition.

(ii) Verify the flight guidance command outputs are capable of display on associated flight displays. Interface specifications shall be verified and determined to be appropriate for the systems identified in the equipment installation instructions.

(iii) Verify that pitch attitude commands do not result in an angle-of-attack exceeding the onset of stall warning or a maximum pitch command of 27°, whichever is less.

(iv) For systems incorporating manual activation of recovery flight guidance commands, verify the system is activated only by the TOGA switches (or equivalent means). For systems providing automatic activation of recovery guidance, verify the system is activated concurrent with the windshear warning alert.

(v) Verify that windshear recovery guidance commands and any automatic recovery mode can be deselected by a means other than the TOGA switches.

(vi) For systems incorporating automatic reversion of flight guidance commands from windshear escape guidance to another flight guidance mode, verify that the transition between flight guidance modes provides smooth guidance information.

(vii) Verify flight guidance commands are not removed from the flight guidance display until either manually deselected or until the aircraft, following exit of the warning conditions, has maintained a positive rate of climb and speed above 1.3 V_{s1} for at least 30 seconds.

verification and validation of the computer software, the following requirements must be met:

(1) RTCA Document No. DO-178A defines three levels of software; Level 1, 2, and 3. The applicant must declare the level (or levels) to which the computer software has been verified and validated. If the equipment incorporates more than one software level, appropriate partitioning of different software levels is required. The software for windshear warning and escape guidance functions must be verified and validated to at least Level 2. An installation safety analysis for a particular aircraft installation should be accomplished to determine if software must be verified and validated to the more stringent Level 1 requirements.

(2) The applicant must submit a software verification and validation plan for review and approval.

NOTE: The FAA strongly recommends early discussion and agreement between the applicant and the FAA on the applicant's proposed software verification and validation plan, and the applicant's proposed software level or levels.

(h) Marking. In addition to the marking specified in Federal Aviation Regulations (FAR) Section 21.607(d), the following information shall be legibly and permanently marked on the major equipment components:

(1) Each separate component of equipment that is manufactured under this TSO must be permanently and legibly marked with at least the name of the manufacturer and the TSO number.

(2) With regard to FAR Section 21.607(d)(2), the part number is to include hardware and software identification, or a separate part number may be utilized for hardware and software. Either approach must include a means for showing the modification status.

(3) The level(s) to which the computer software has been verified and validated.

(i) Operating instructions.

(ii) Equipment limitations.

(iii) Installation procedures and limitations.

(iv) Schematic drawings as applicable to the installation procedures.

(v) Wiring diagrams as applicable to the installation procedures.

(vi) Specifications.

(vii) List of major components (by part number) that make up the equipment system complying with the standards prescribed in this TSO.

(viii) An environmental qualifications form as described in RTCA Document DO-160B for each component of the system.

(ix) Manufacturer's TSO qualification test report.

(x) Nameplate drawing.

(xi) The appropriate documentation as defined in RTCA Document DO-178A, or equivalent, necessary to support the verification and validation of the computer software to Level 1 or 2. If the software is verified and validated to more than one level, the appropriate documentation for all such levels must be submitted.

(2) In addition to those data requirements that are to be furnished directly to the FAA, each manufacturer must have available for review by the Manager of the ACO having purview of the manufacturer's facilities, the following technical data:

(i) A drawing list, enumerating all of the drawings and processes that are necessary to define the article's design.

(v) Schematic drawings.

(vi) Wiring diagrams.

(vii) Documentation to support the computer software verification and validation plan for Level 1 or 2 software.

(viii) The appropriate documentation as defined in RTCA Document DO-178A, or equivalent, necessary to support the verification and validation of the computer software to Level 1 or 2. If the software is verified and validated to more than one level, the appropriate documentation for all such levels must be available for review.

(ix) The results of the environmental qualification tests conducted in accordance with RTCA Document DO-160B.

(j) Data to be Furnished with Manufactured Units. One copy of the data and information specified in paragraphs (i)(1)(i) through (viii) of this TSO, and instructions for periodic maintenance and calibration which are necessary for continued airworthiness must go to each person receiving for use one or more articles manufactured under this TSO. In addition, a note with the following statement must be included:

> "The conditions and tests required for TSO approval of this article are minimum performance standards. It is the responsibility of those desiring to install this article either on or within a specific type of class of aircraft to determine that the aircraft installation conditions are within the TSO standards. The article may be installed only if further evaluation by the applicant documents an acceptable installation and is approved by the Administrator."

(k) Availability of Reference Documents.

(1) Copies of RTCA Document Nos. DO-160B and DO-178A may be purchased from the Radio Technical Commission for

of Airborne Windshear Alerting and Flight Guidance Systems"; may be reviewed at FAA Headquarters in the Aircraft Certification Service, Aircraft Engineering Division (AIR-100), and at all regional ACO's.

Daniel P. Salvano
Acting Manager, Aircraft Engineering
Division, AIR-100

The downburst model parameters below provide the variables to be used to obtain the representative test conditions: (1)(2)

Radius of Downdraft (ft)	Maximum Outflow (ft/s)	Altitude of Max. Outflow (ft)	Distance From Starting Point (3) (ft)
920	37	98	20000 (-9000)
1180	47.6	98	15000 (-14000)
2070	58.4	131	25000 (-4000)
4430	68.9	164	30000 (1000)
9010	72.2	262	30000 (1000)
3450	88.2	197	25000 (-4000)
3180	53.1	262	30000 (1000)
1640	46	164	25000 (-4000)
5250	81.3	197	30000 (1000)
1250	67.6	100	25000 (-4000)

(1) From analytic microburst model documented in NASA TM-100632. These parameters are based on data from Proctor's TASS model.

(2) For the takeoff case, the downburst center is positioned at the point the aircraft lifts off the runway for all test cases.

(3) For the approach/landing case, the downburst center is positioned as stated. The test is begun with the aircraft at an initial altitude of 1500 feet on a 3° glideslope (touchdown point approximately 29000 feet away). Distance from starting point indicates where the center of the downburst shaft is located relative to the starting point. The number in parenthesis next to it indicates the relative distance of the microburst center from the touchdown point (not the end of the runway). A negative number indicates that the microburst center is located before the touchdown point, positive indicates it is past the touchdown point.

the mass continuity equation in cylindrical coordinates. Altitude dependence, including boundary layer effects near the ground, closely matches real-world measurements, as do the increase, peak, and decay of outflow and downflow with increasing distance from the downburst center. Equations for horizontal and vertical winds were derived, and found to be infinitely differentiable, with no singular points existent in the flow field. In addition, a simple relationship exists among the ratio of maximum horizontal to vertical velocities, the downdraft radius, depth of outflow, and altitude of maximum outflow. In use, a microburst can be modeled by specifying four characteristic parameters. Velocity components in the x, y, and z directions, and the corresponding nine partial derivatives are obtained easily from the velocity equations.

INTRODUCTION

Terminal area operation of transport aircraft in a windshear environment has been recognized as a serious problem. Studies of aircraft trajectories through downbursts show that specific guidance strategies are needed for aircraft to survive inadvertent downburst encounters. In order for guidance strategies to perform in simulations as in actual encounters, a realistic set of conditions must be present during development of the strategies. Thus, airplane and wind models that closely simulate real-world conditions are essential in obtaining useful information from the studies.

Wind models for use on personal computers, or for simulators with limited memory space availability, have been difficult to obtain because variability of downburst characteristics makes analytical models unrealistic, and large memory requirements make use of numerical models impossible on any except very large capacity computers.

Bray [ref. 1] developed a method for analytic modeling of windshear conditions in flight simulators, and applied his method in modeling a multiple downburst scenario from Joint Airport Weather Studies (JAWS) data. However, the altitude dependence of his model is not consistent with observed data, and, although flexibility in sizing the downbursts is built into the model, it does not maintain the physical relationships which are seen in real-world data among the sizing parameters. In particular, and then implemented in a pilot in the loop simulation using a very simple wind model in both efforts [fig. 1]. This model consisted of a constant outflow outside of the downburst radius and a constant slope headwind to tailwind shear across the diameter of the downburst. It was recognized that a more realistic wind model could significantly alter the outcome of the trajectory. For the subsequent part of this study, which involves altering the airplane model to simulate approach to landing and escape maneuvers and additional takeoff cases, a more realistic wind model was preferred. The simple analytical model outlined in this report was developed for this purpose.

SYMBOLS

JAWS	Joint Airport Weather Studies
NIMROD	Northern Illinois Meteorological Research on Downbursts
R	radius of downburst shaft (ft)
r	radial coordinate (distance from downburst center) (ft)
TASS	Terminal Area Simulation System
u	velocity in r-direction (or x-direction) (kts)
v	velocity in y-direction (kts)
w	velocity in z-direction (kts)
w_{max}	magnitude of maximum vertical velocity (kts)
u_{max}	magnitude of maximum horizontal velocity (kts)
x	horizontal (runway) distance, airplane to downburst center (ft)
y	horizontal (side) distance, airplane to downburst center (ft)
z	airplane altitude above ground level (ft)
z_h	depth of outflow (ft)
z_m	height of maximum U-velocity (ft)
z_{m2}	height of half maximum U-velocity (ft)
z^*	characteristic height, out of boundary layer (ft)
ε	characteristic height, in boundary layer (ft)
λ	scaling factor (s^{-1})

DEVELOPMENT OF VELOCITY EQUATIONS

Beginning with the full set of Euler and mass continuity equations, some simplifying assumptions about the downburst flow conditions were made. Effects of viscosity were parameterized

$$\nabla \cdot V = 0 \,. \tag{1}$$

Written out in full, equation 2 is

$$\frac{\partial u}{\partial r} + \frac{\partial w}{\partial z} + \frac{u}{r} = 0 \,. \tag{2}$$

This equation is satisfied by solutions of the form

$$w = g\,(r^2)\,q(z) \tag{3a}$$

$$u = \frac{f(r^2)}{r}\,p(z) \tag{3b}$$

provided that

$$f'(r^2) = \frac{\lambda}{2}\,g\,(r^2) \tag{4a}$$

$$q'(z) = -\lambda p(z) \,. \tag{4b}$$

Note that $f'(r^2) = \dfrac{\partial f(r^2)}{\partial r^2}$. To solve this system of equations, solutions were assumed for two of the functions and the other two were obtained from equations 4a and 4b.

It was desired that the velocity profiles of this analytic model exhibit the altitude and radial dependence shown in the large-scale numerical weather model TASS (Terminal Area Simulation System) [ref. 3,4]. The TASS model is based on data from the Joint Airport Weather Studies (JAWS) [ref. 5], and provides a three-dimensional velocity field, frozen in time, for given locations of an airplane within the shear [ref. 6]. Figure 2 shows dimensionless vertical profiles of horizontal velocity, u, for TASS data, laboratory data obtained by impingement of a jet on a flat plate, and data from NIMROD (Northern Illinois Meteorological Research on Downbursts) [ref. 7]. Specific points of interest are the maximum horizontal velocity (located 100 - 200 meters above the ground), below which is a decay region due to boundary layer at a given radius, with a smooth, nearly linear transition between the two. Beyond the peaks, the velocity should show an exponential decay to zero. The vertical velocity was required to have a peak along the axis of symmetry (r=0), and decay exponentially at increasing radius.

A pair of shaping functions that gave velocity profiles matching TASS data as required are given below.

$$g(r^2) = e^{-(r/R)^2}$$

$$p(z) = e^{-z/z^*} - e^{-z/\varepsilon}$$

The remaining solutions were found by integrating equations 4a and 4b, yielding:

$$f(r^2) = \frac{\lambda R^2}{2}\left[1 - e^{-(r/R)^2}\right]$$

$$q(z) = -\lambda\left\{\varepsilon\left(e^{-z/\varepsilon} - 1\right) - z^*\left(e^{-z/z^*} - 1\right)\right\}.$$

Figures 4 and 5 show plots of these shaping functions.

Combining the functions as in equation 3, the horizontal and vertical velocities are expressed as

$$u = \frac{\lambda R^2}{2r}\left[1 - e^{-(r/R)^2}\right]\left(e^{-z/z^*} - e^{-z/\varepsilon}\right) \quad (5)$$

$$w = -\lambda e^{-(r/R)^2}\left[\varepsilon\left(e^{-z/\varepsilon} - 1\right) - z^*\left(e^{-z/z^*} - 1\right)\right]. \quad (6)$$

By taking derivatives of equations 5 and 6 with respect to r and z, respectively, and substituting in equation 2, it can be shown that the velocity distributions satisfy continuity.

The parameters z* and ε were defined as characteristic scale lengths associated with "out of boundary layer" and "in boundary layer" behavior, respectively. Analysis of TASS data indicated that $z^* = z_{m2}$, the altitude at which the magnitude of the horizontal velocity is half the maximum value.

derivative is

$$2\left(\frac{r}{R}\right)^2 = e^{-(r/R)^2} - 1 .$$

The resulting equation for the z-derivative is

$$\frac{z_m}{z^*} = \frac{1}{(z^*/\varepsilon) - 1}\ln(z^*/\varepsilon) .$$

Recalling that $z_m/z^* = 0.22$, the values 1.1212 and 12.5 were obtained from iteration for the ratios r/R and z^*/ε, respectively.

Using these values, the maximum horizontal velocity can be expressed as $u_{max} = 0.2357\,\lambda\, R$. The maximum vertical wind is located at r = 0 and z = z_h, by definition, and is given by $w_{max} = \lambda z^*(e^{-(z_h/z^*)} - 0.92)$.

A ratio of maximum outflow and downflow velocities can be formed

$$\frac{u_m}{w_m} = \frac{0.2357R}{z^*(e^{-(z_h/z^*)} - 0.92)} .$$

The scaling factor, λ, was determined by using either of equations 5 or 6 for horizontal or vertical velocity, and setting it equal to the maximum velocity, u_{max} or w_{max}, respectively. Solving for λ resulted in:

$$\lambda = \frac{w_m}{z^*(e^{-(z_h/z^*)} - 0.92)} = \frac{u_m}{0.2357R} .$$

The velocity equations were easily converted to rectangular coordinates, as shown in the Appendix. Partial derivatives with respect to x, y, and z were obtained by differentiating the velocity equations, and are also listed in the Appendix.

mately half the value at the peak outflow radius. The vertical wind profiles were taken at the radius of peak downflow ($r = 0$) and at $r = 0.3$ R. Horizontal wind and vertical wind profiles in figure 7 were taken at altitudes of $h = z_m$ (maximum outflow), $h = z^*$ (half-maximum outflow), and $h = z_h$ (depth of outflow).

This analytical model is compared with TASS, laboratory, and NIMROD data in figure 8. The figure shows that, when nondimensionalized by the altitude of half-maximum outflow (z^*) and by the maximum outflow ($u = u_{max}$), the analytical model agrees closely with the other data.

Different shears can be modeled by specifying four parameters, and the location of downburst center relative to the airplane flying through it. The four parameters are: 1) a characteristic horizontal dimension; 2) maximum wind velocity; 3) altitude of maximum outflow; and 4) depth of outflow. The characteristic horizontal dimension specified is the radius of the downdraft column, noting that this is about 89 percent of the radius of peak outflow. The maximum wind velocity can be either horizontal or vertical.

CONCLUDING REMARKS

The analytic microburst model developed for use in real-time and batch simulation studies was shown to agree well with real-world measurements for the cases studied. The functions chosen for the model showed boundary-layer effects near the ground, as well as the peak and decay of outflow at increasing altitudes, and increasing downflow with altitude. The exponential increase and decay of downflow and outflow (in the radial direction) are also characterized by the model. Equations for horizontal and vertical winds are simple and continuously differentiable, and partial derivatives in rectangular or cylindrical coordinates can be easily obtained by direct differentiation of the velocity equations. The governing equation for this system is the mass conservation law, and the analytic velocity functions developed here satisfied this condition. The model is sustained by a strong physical basis and yields high fidelity results, within the limitations of maintaining simplicity in the model, and variability of the microburst phenomenon. Parameterization of some of the characteristic dimensions allows flexibility in selecting the size and intensity of the microburst.

Shear Encounters. Master's Thesis, George Washington University, January 1988.

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5. Frost, W.: Modeling and Implementation of Wind Shear Data. Wind Shear/Turbulence Inputs to Flight Simulation and Systems Verification, NASA CP-2474, 1987, pp. 49-66.

6. Proctor, F. H.: NASA Wind Shear Model -- Summary of Model Analyses. Airborne Wind Shear Detection and Warning Systems, NASA CP-10006, 1988, pp. 29-66.

7. Fujita, T. T.: Tornadoes and Downbursts in The Context of Generalized Planetary Scales. Journal of Atmospheric Sciences, vol. 38, no. 8, August 1981, pp. 1511-1534.

$$e_z = e^{-(h/z^*)}$$

Horizontal and Vertical Velocities

$$w_x = \frac{\lambda R^2}{2r^2}(1-e_r)e_d x_{ad}$$

$$w_y = \frac{\lambda R^2}{2r^2}(1-e_r)e_d y_{ad}$$

$$w_h = -\lambda e_r e_c$$

Partial Derivatives

$$\frac{\partial w_x}{\partial x} = \frac{\lambda R^2 e_d}{2r^2}[e_r(\frac{2x_{ad}^2}{R^2} + \frac{2x_{ad}^2}{r^2} - 1) - \frac{2x_{ad}^2}{r^2} + 1]$$

$$\frac{\partial w_x}{\partial y} = \frac{\lambda R^2 x_{ad} y_{ad} e_d}{r^2}[e_r(\frac{1}{R^2} + \frac{1}{r^2}) - \frac{1}{r^2}]$$

$$\frac{\partial w_x}{\partial h} = \frac{\lambda R^2 x_{ad}}{2r^2}(1-e_r)[\frac{e_e}{\varepsilon} - \frac{e_z}{z^*}]$$

$$\frac{\partial w_y}{\partial x} = \frac{\lambda R^2 x_{ad} y_{ad} e_d}{r^2}[e_r(\frac{1}{R^2} + \frac{1}{r^2}) - \frac{1}{r^2}]$$

$$\frac{\partial w_y}{\partial y} = \frac{\lambda R^2 e_d}{2r^2}[e_r(\frac{2y_{ad}^2}{R^2} + \frac{2y_{ad}^2}{r^2} - 1) - \frac{2y_{ad}^2}{r^2} + 1]$$

$$\frac{\partial w_y}{\partial h} = \frac{\lambda R^2 y_{ad}}{2r^2}(1-e_r)[\frac{e_e}{\varepsilon} - \frac{e_z}{z^*}]$$

$$\frac{\partial w_h}{\partial x} = \frac{2\lambda x_{ad} e_r e_c}{R^2}$$

$$\frac{\partial w_h}{\partial y} = \frac{2\lambda y_{ad} e_r e_c}{R^2}$$

$$\frac{\partial w_h}{\partial h} = -\lambda e_r e_d$$

$$W_{y_{max}} = W_{x_{max}}$$

$$W_{h_{max}} = \lambda z^* e^{-(z_h/z^*)} - 0.92)\ .$$

(λ is determined from the above relationships)

$$\frac{W_{x_{max}}}{W_{h_{max}}} = \frac{0.2357R}{z^*(e^{-z_h/z^*} - 0.92)}$$

<u>Variable List</u>

z^* = altitude where w_x is half the value of $w_{x_{max}}$ (ft)

ε = characteristic height of boundary layer effects (ft)

z_h = depth of outflow (ft)

z_m = altitude of maximum outflow (ft)

λ = scaling parameter (s^{-1})

r = radial distance from airplane to downburst (ft)

h = altitude of airplane (ft)

R = radius of downdraft (ft)

x_{ad}, y_{ad} = x,y coordinates, airplane to microburst (ft)

$w_{x_{max}}, w_{y_{max}}, w_{h_{max}}$ maximum winds, x, y, and h directions

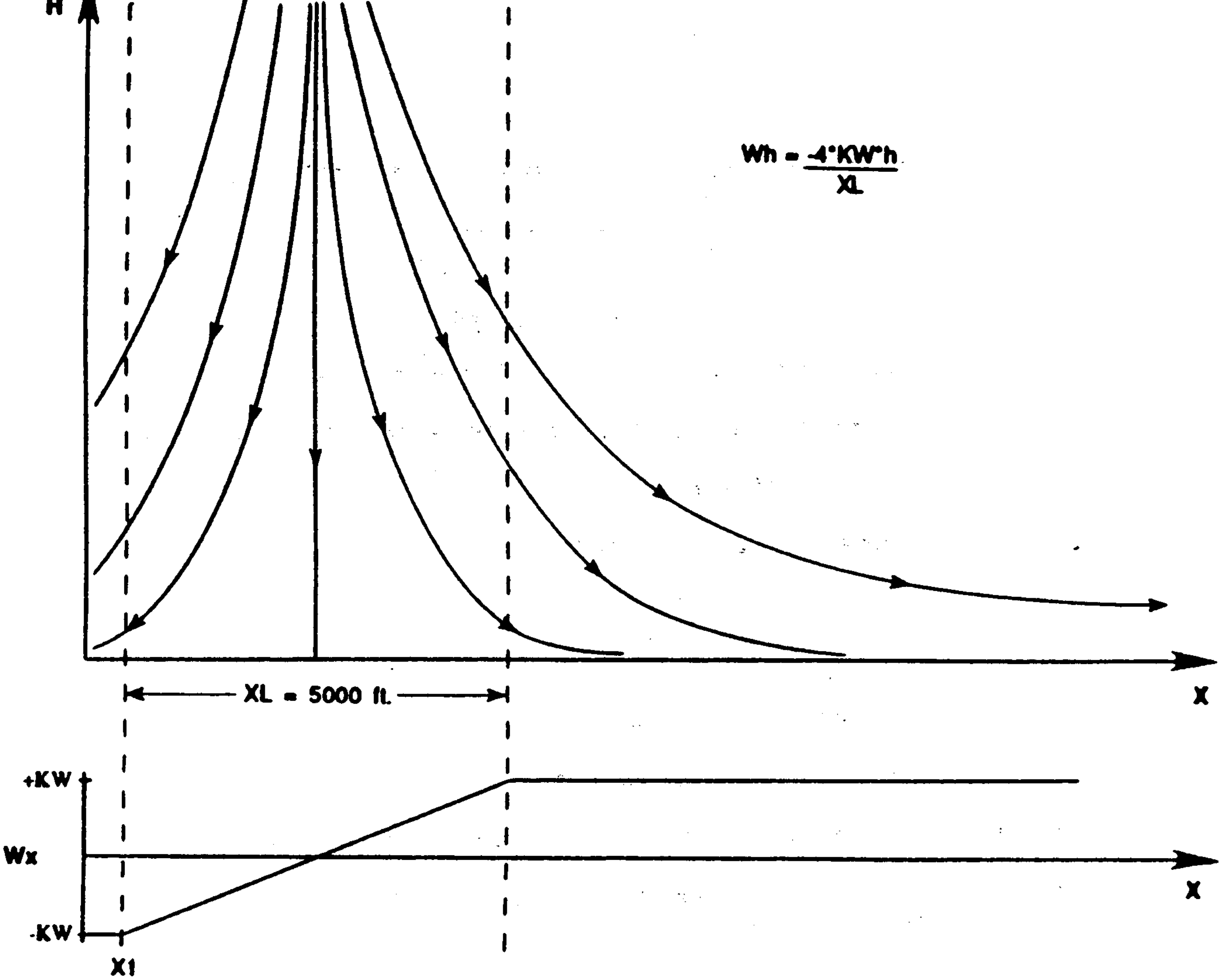

Figure 1 Wind Model Used In Guidance Studies

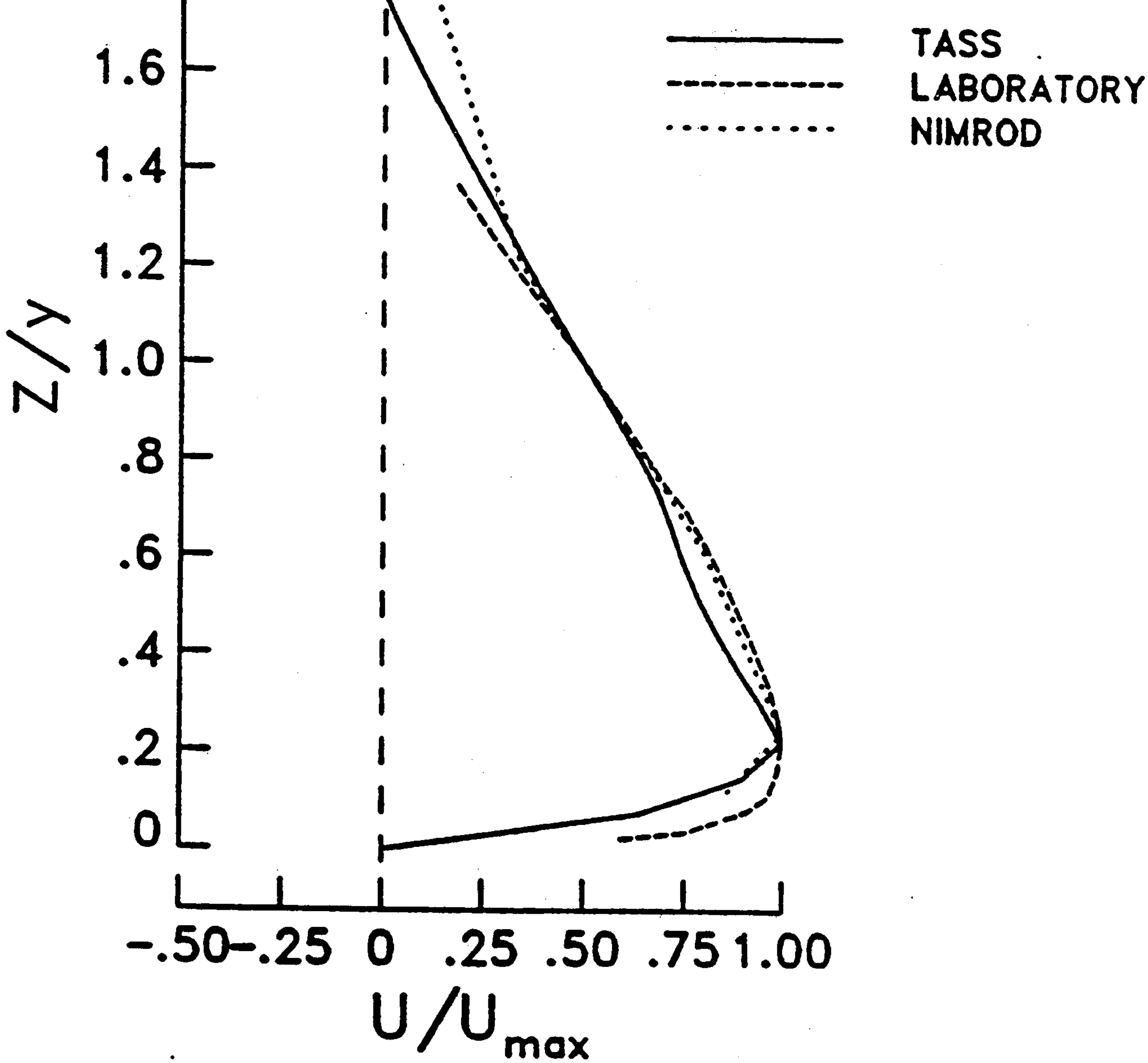

Figure 2 Vertical Profile of Microburst Outflow (Nondimensional)

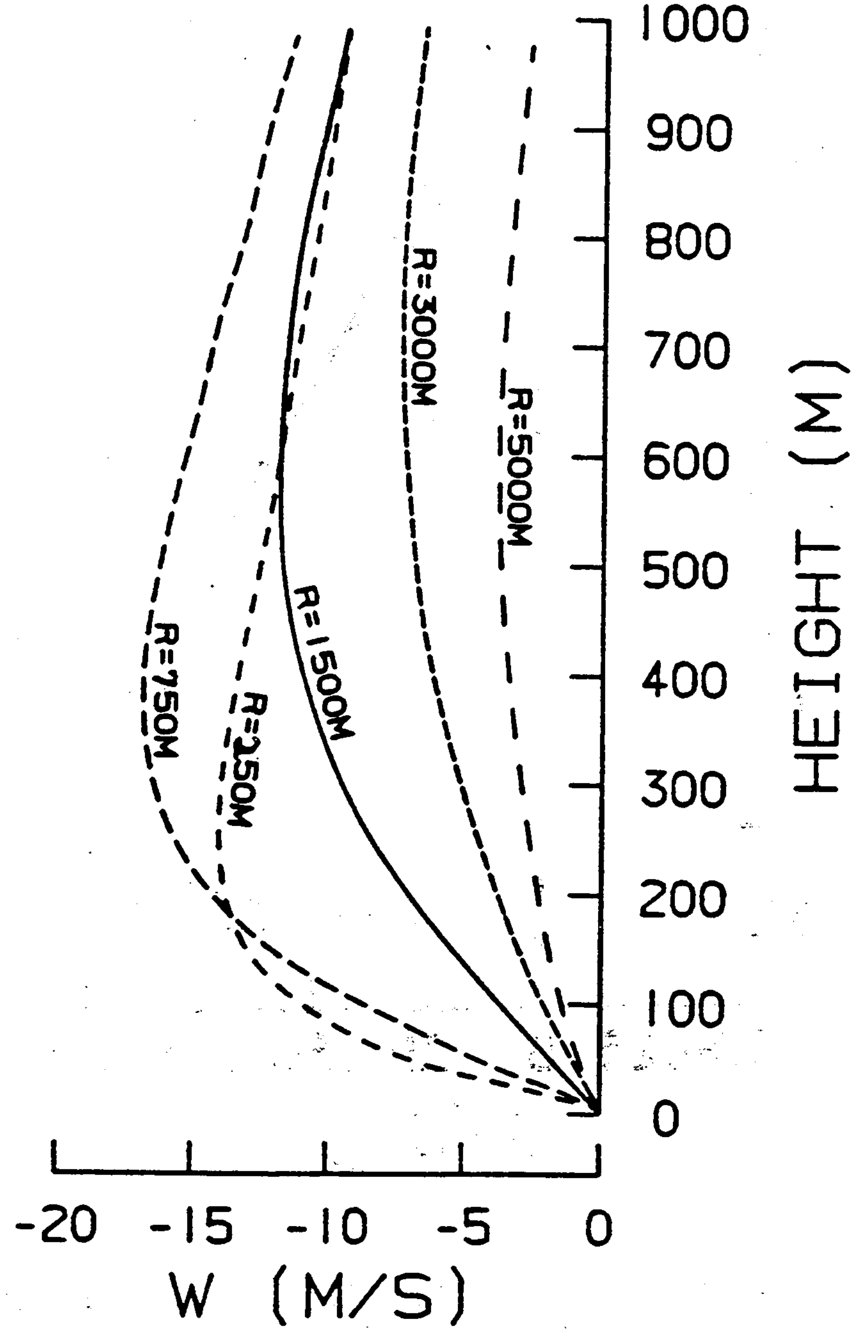

Figure 3 Vertical Profile of Microburst Downflow

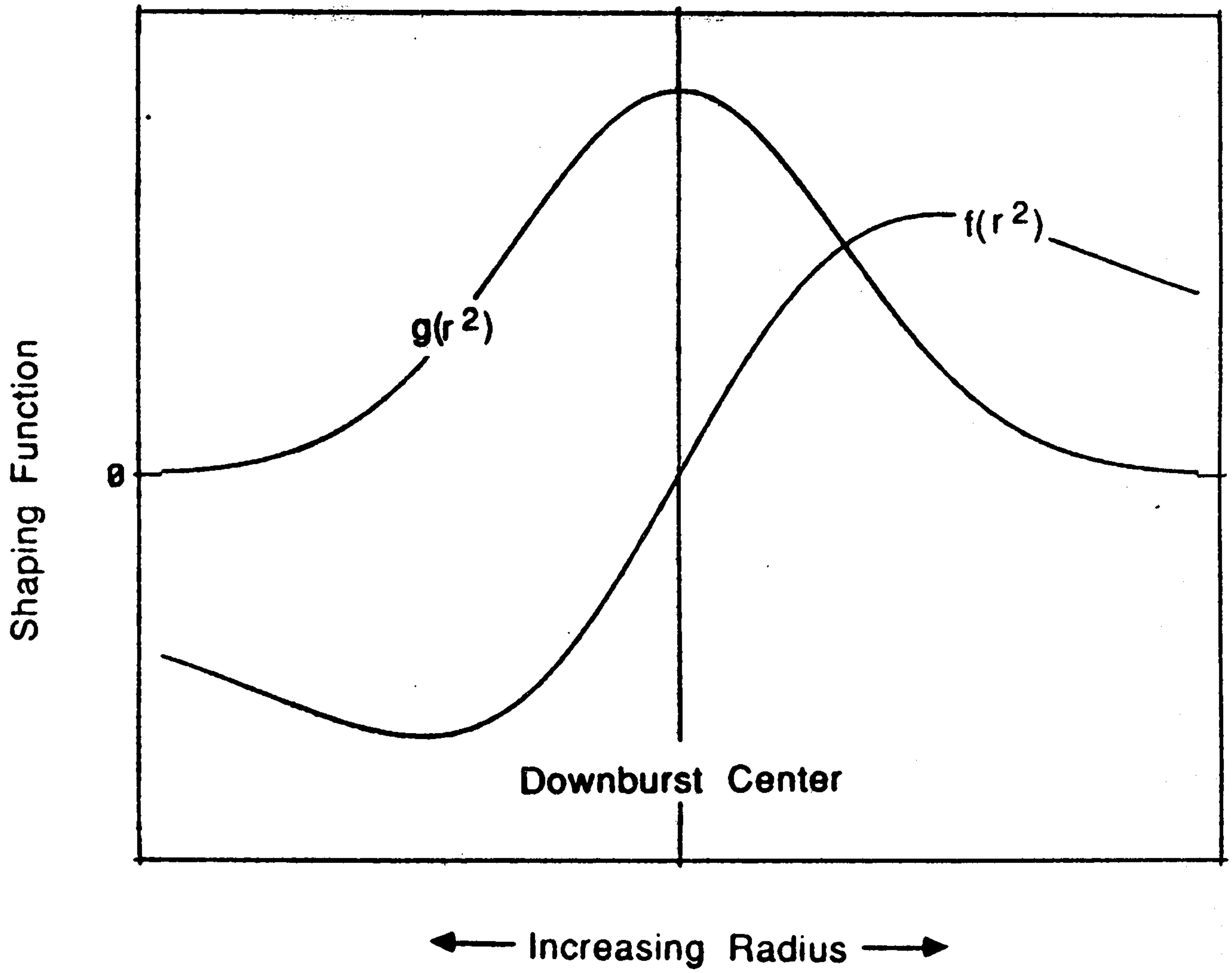

Figure 4 Characteristic Variation of Horizontal Shaping Functions

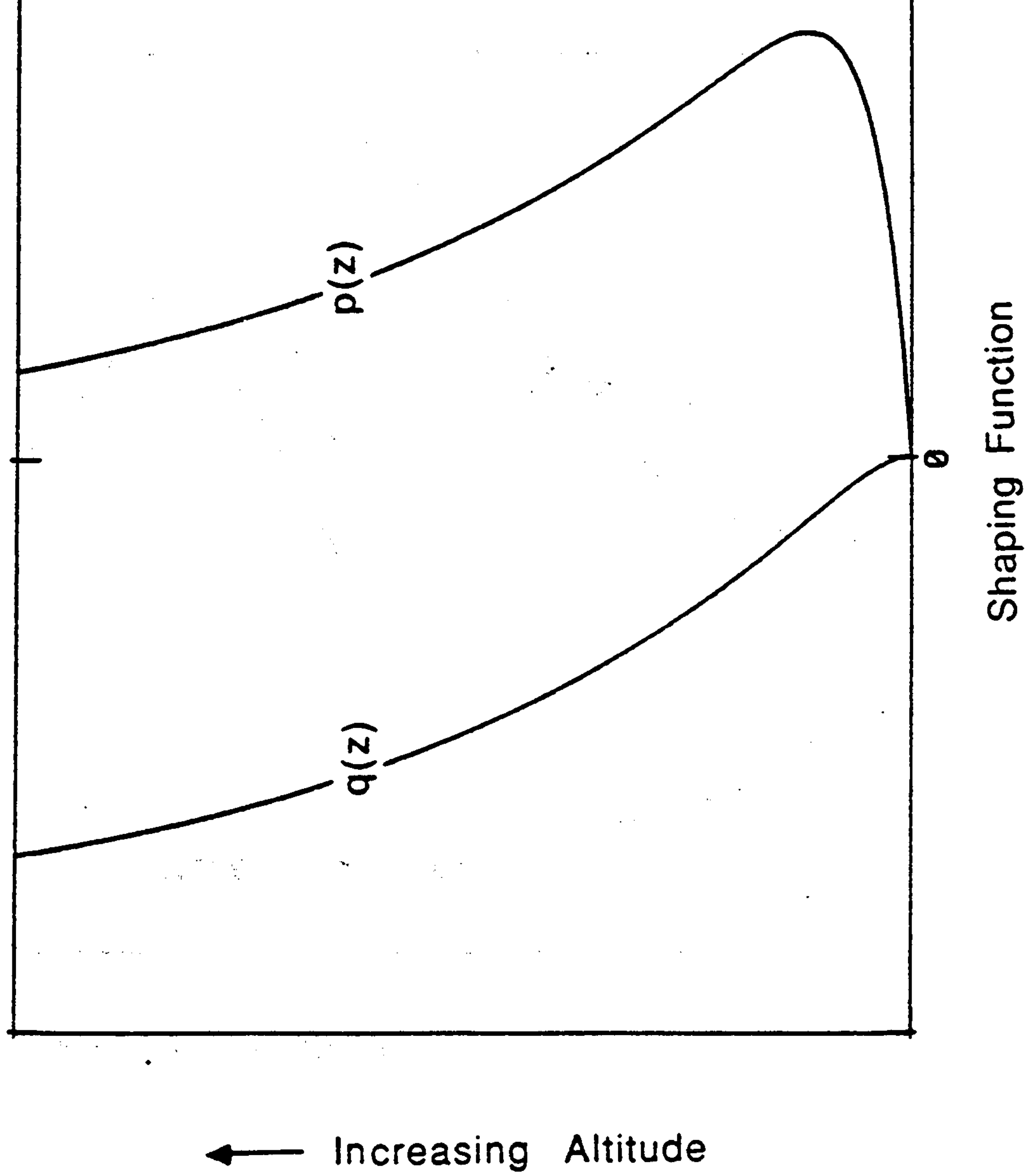

Figure 5 Characteristic Variation of Vertical Shaping Functions

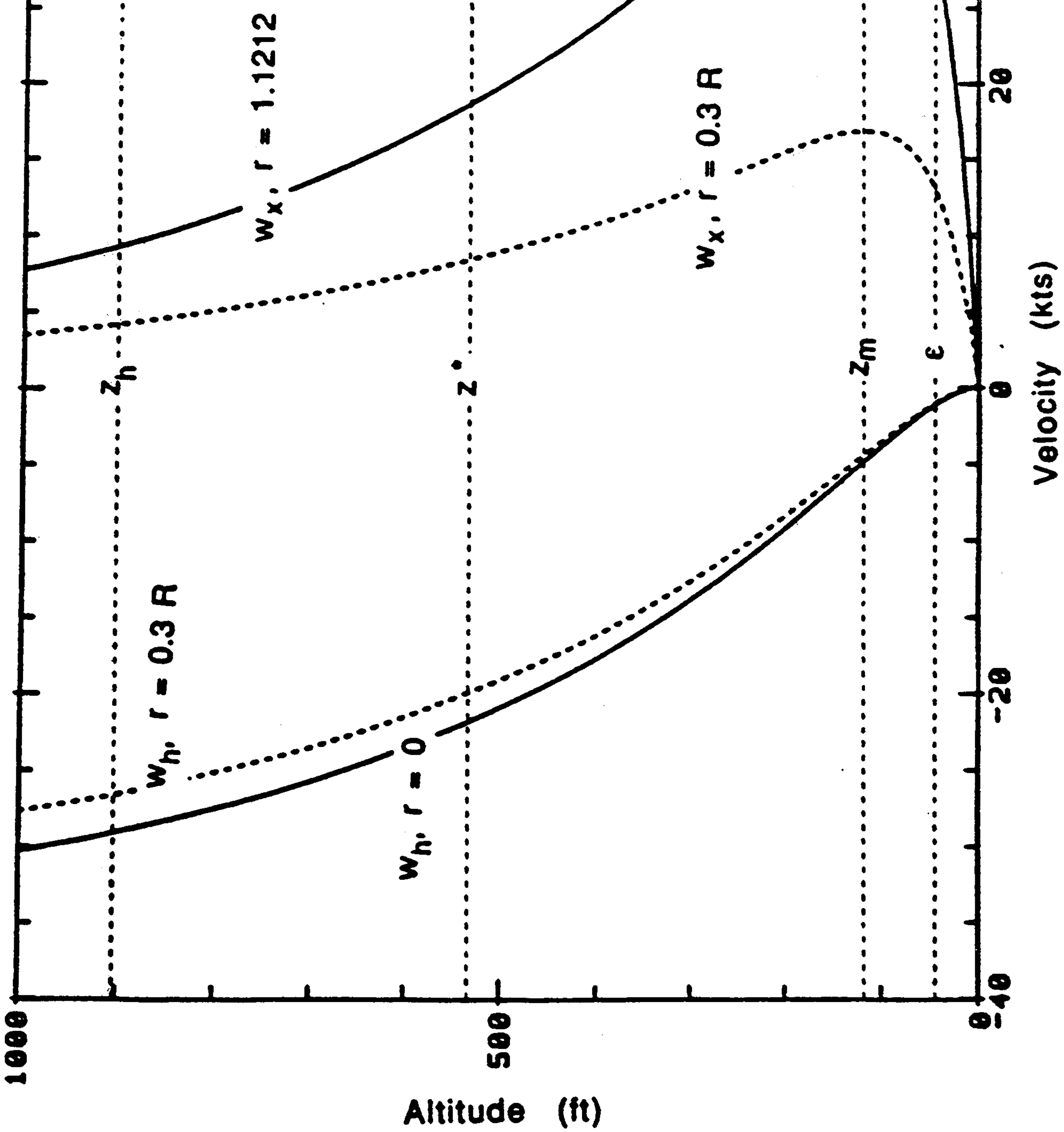

Figure 6 Vertical Velocity Profiles For Analytical Model

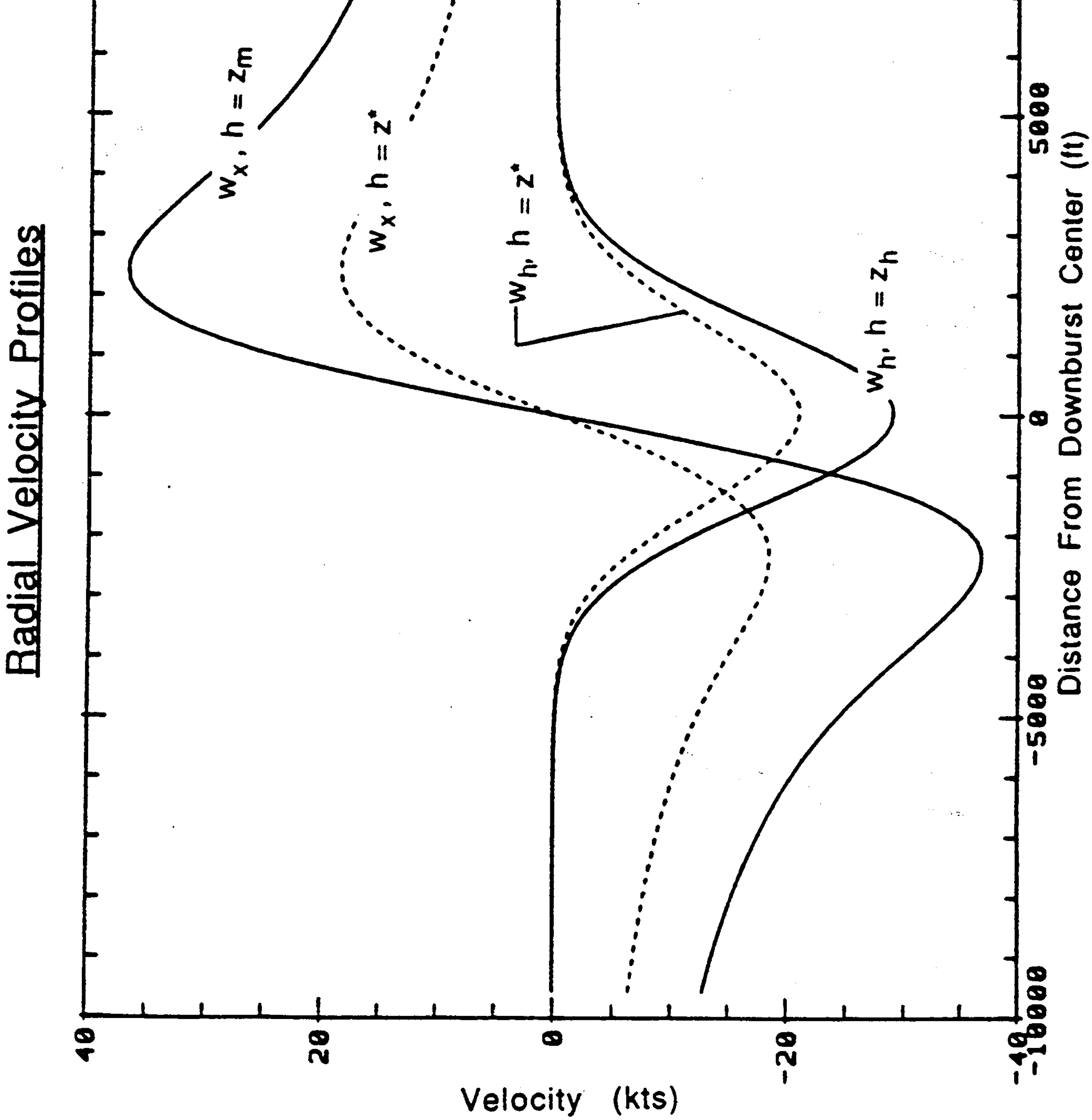

Figure 7 Radial Velocity Profiles For Analytical Model

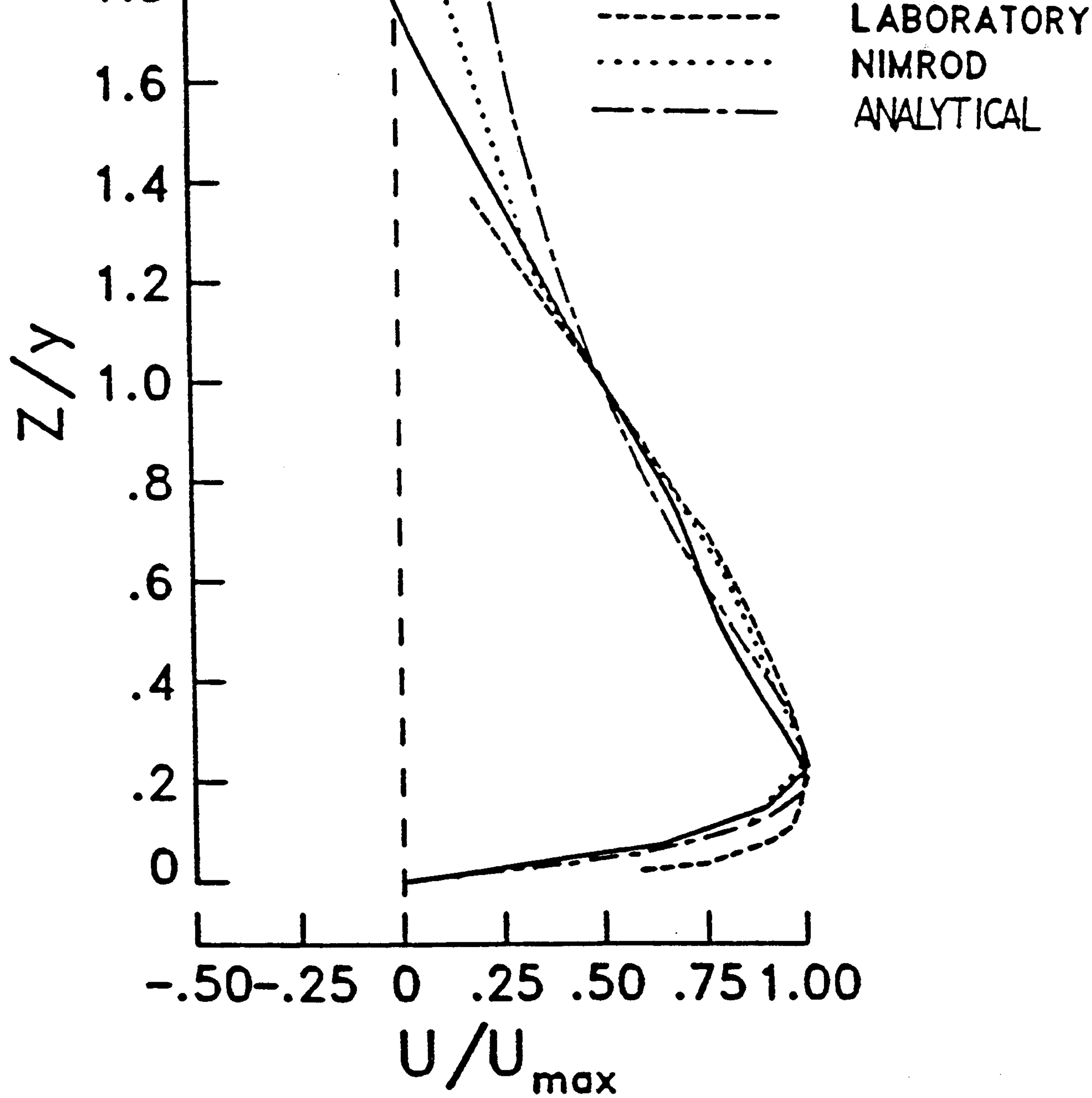

Figure 8 Comparison of Wind Model Vertical Profiles

(c)(3)(iii) of this AC.

Dryden Turbulence Model

```
Fu(S) = SIGMAu * SQRT (TAUu/PI) * 1/(1+TAUu*S)

Fv(S) = SIGMAv * SQRT (TAUv/PI2) *     (1+SQRT3*TAUv*S)
                                      ----------------------
                                      (1+TAUv*S)*(1+TAUv*S)

Fw(S) = SIGMAw * SQRT (TAUw/PI2) *     (1+SQRT3*TAUw*S)
                                      ----------------------
                                      (1+TAUw*S)*(1+TAUw*S)
```

where:
- SIGMAu, SIGMAv, SIGMAw are the RMS intensities;
- TAUu = Lu/VA;
- TAUv = Lv/VA;
- TAUw = Lw/VA;
- Lu, Lv, Lw are the turbulence scale lengths;
- VA is the aircraft's true airspeed (ft/sec);
- PI = 3.1415926535;
- PI2 = 6.2831853070 (2 times PI);
- SQRT3 = 1.732050808 (square root of 3); and
- S is the Laplace transform variable.

The following table lists SIGMAu, SIGMAv, SIGMAw, Lu, Lv, and Lw versus altitude. Extrapolation will not be used, and simulator altitudes outside the bounds of the turbulence list will use the data at the boundary.

Altitude	RMS Intensities (ft/sec)			Scale Lengths (feet)		
(feet)	Long	Lat	Vert	Long	Lat	Vert
100	5.6	5.6	3.5	260	260	100
300	5.15	5.15	3.85	540	540	300
700	5.0	5.0	4.3	950	950	700
900	5.0	5.0	4.45	1123	1123	900
1500	4.85	4.85	4.7	1579	1579	1500

The applicant must demonstrate that the variance of their turbulence implementation is adequate.

A	OMEGA (rad/sec)	Approx. Gust Duration (sec)
7.5	2.1	3
7.5	1.26	5
7.5	0.78	8
7.5	0.63	10
7.5	0.52	12
7.5	0.42	15
7.5	0.31	20

where

$\dot{w}_x$ = Horizontal component of the wind rate of change expressed in g units (1.91 kts/sec = 0.1 g) (positive for increasing headwind).

w_h = Vertical component of the wind vector w (ft/sec) (positive for downdraft).

V = True airspeed (ft/sec).

g = Gravitational acceleration (ft/sec^2).

of the Honeywell Company.

The Wind Shear Simulation Model (WSSM) is a point mass three-degree of freedom mathematical model which simulates the motion of an aircraft in a vertical plane. The equations of motion, which are described in the wind axes, include the wind components of velocity and acceleration so that the aircraft dynamics during a windshear encounter are accurately modeled. This model has been used by several investigators to study the behavior of an aircraft during windshear encounters.

<u>The Equations of Motion</u>

The motion of a constant mass point in the vertical plane may be described by four equations of state and a control variable. For an aircraft it is convenient to use an orthogonal reference frame which is attached to the frame of the aircraft and its x-direction points in the direction of motion. Such a reference frame is the relative wind reference frame.

The following equations model the states of the aircraft in the wind axes:

$$\begin{aligned}\text{Vdt} = {} & \text{g}[(\text{T.csalf}) - \text{D})/\text{W} - \text{sngam}] - \text{Wxdt.csgam} \\ & - \text{Wzdt.sngam}\end{aligned} \tag{1}$$

$$\begin{aligned}\text{Gdt} = {} & \{\text{g}[(\text{T.snalf} + \text{L})/\text{W} - \text{csgam}] + \text{Wxdt.sngam} \\ & - \text{Wzdt.csgam}\}/\text{V}\end{aligned} \tag{2}$$

$$\text{Hdt} = \text{V.sngam} + \text{Wz} \tag{3}$$

$$\text{Xdt} = \text{V.csgam} + \text{Wx} \tag{4}$$

D = Total drag in lbs.
W = Gross weight in lbs.
sngam = sin(gamma)
gamma = Flight path angle in radians
Wxdt = Inertial windshear x-component in knots/sec
Gdt = Rate of change of gamma in rad/sec
snalf = sin(alpha)
L = Total lift in lbs.
V = True airspeed in knots
Hdt = Altitude rate in knots
Wz = Inertial wind z-component in knots
Xdt = Ground speed in knots

In the above equations, positive directions are upwards and forwards. This implies that tail winds and updrafts are positive while head winds and downdrafts are negative. All states can be determined from a given alpha; therefore, alpha is the control variable.

Since the model is that of a point mass, it is necessary to introduce the concept of alpha_command and actual alpha to account for the effect of the horizontal tail/elevator. This is done by introducing a lag between alpha_command and the actual alpha. Therefore, any command that is given to the elevator or stabilizser can be interpreted as an alpha_command which will cause a change in angle of attack.

From equations 1, 2, 3, and 4 it can be seen that any change in alpha will produce a change in the longitudinal and normal accelerations which in turn will change the states of the aircraft.

The Path Control Function

The different segments of the trajectory flown by the WSSM are described by a series of alpha_commands which are generated by the procedure explained below.

1. The aircraft is trimmed for the initial conditions specified by the user. Initial conditions are usually specified as altitude, gross weight, flaps, speed, flight path angle, and wind characteristics. The trimming operation consists in finding the angle of attack that satisfies the equations of state and will result in an unaccelerated motion.

3. In order to specify an alpha_command the user must supply a subroutine where a quadratic function is defined in such a way that when minimized with respect to alpha, and constrained by the equations of state, the minimizing alpha will produce the desired path in an optimal manner. For example, if we want to fly initially at a constant path angle, say 8 degrees, then the quadratic function may be defined by the expression:

$$\text{cst} = (\text{gamma} + \text{Gdt*dt} - 8/57.3)^2 \tag{5}$$

where:
cst = Function to be minimized w/r/t alpha
dt = Time increment used in simulation in sec.

The term Gdt*dt is a predictive term which anticipates the change in gamma.

Other expressions follow:

$\text{cst} = (\text{V} + \text{Vdt*dt} - \text{V\_cmd})^2$ Constant speed

$\text{cst} = (\text{alpha} + \text{gamma} + \text{Gdt*dt} - \text{pitch\_cmd})^2$ Constant pitch

The minimization of the function cst is performed by a subroutine at each time frame and is totally transparent to the user, who has to supply only the objective function cst.

4. Each expression defining a different value of the objective function cst is called a "LAW". The user selects the guidance law to be used during the windshear encounter at menua time. This method allows the user to compare different guidance laws under the exact same conditions.

<u>The Wind Models</u>

The WSSM has two types of wind models: the Dallas-Ft Worth accident wind field simulated by a quad_vortex model, and the constant shear model which is user defined via the initial conditions menu.

The WSSM is written in Microsoft QuickBasic which is a highly structured language with a very friendly full page editor. QuickBasic is very convenient for development since it allows the user to stop execution, change the program and continue executing. It also interfaces with Microsoft FORTRAN, C, or assembly language.

The procedure suggested for this application is that the WSSM be compiled without subroutines DETECT and GUIDE. DETECT and GUIDE can be separately compiled and put in a library called WNDSHR.QLB. These external subroutines may be written in Microsoft FORTRAN, C, or assembly language.

```
    DECLARE SUB WINDS ()
    DECLARE SUB OPT ()
    DECLARE SUB MIN (DM, M2, C1, C2, C3, M)
    DECLARE SUB BEGIN ()
    DECLARE SUB VSHAKER ()
    DECLARE SUB COST ()
    DECLARE SUB LIMIT ()
    DECLARE SUB RATES ()
    DECLARE SUB THRUST ()
    DECLARE SUB ATMOS ()
    DECLARE SUB PRINTS ()
    DECLARE SUB DRAGS ()

    COMMON SHARED FLPS%, GEAR%, GEAR$, CL, CD, LIFT, DRAG, ALPHA
    COMMON SHARED SEC, ALT, DST, HDOT, ALF, GAM, GAMREF, GREF, G
    COMMON SHARED WSALERT%, WX0, WL, WX, WXDT, WZ, WZDT, DFW%
    COMMON SHARED WV, LC%, GM, GREFF, NOSAVE, GM0
    COMMON SHARED DELTA, ISA, T0, SPDSND, VT, VC, MACH, A0, TAT,
TAMF
    COMMON SHARED THRST, EPR, TFCT, APPFLG%
    COMMON SHARED SNGM, CSGM, CSAL, SNAL, VDOT, WG, GDOT, XDOT
    COMMON SHARED AWX, AWZ, AU, AZ, VG, GRND, KF1, GMIN, KF2
    COMMON SHARED ACMD, OLDALF, DT, HP, LP, ALFLIM
    COMMON SHARED LAW%, GMR, ASS, CST, VT0, GCMD
    COMMON SHARED OUTFILE$, DM, ALT1, PL$, TTT, WXDT0, TDX, TSH,
WZ0, TDZ, TSV
    COMMON SHARED GM1, VTP, THETA
    COMMON SHARED ALFRTE, PLMFLG%

    '********************************************
    '                MAIN PROGRAM               *
    '********************************************

START: '<----------<<    RE-RUNS START HERE

    CLOSE : CLEAR
    COLOR 15, 1: CLS : VIEW PRINT
    LOCATE 8, 23: PRINT "      WINDSHEAR SIMULATION"
    LOCATE 10, 23: PRINT "              FOR            "
    LOCATE 12, 23: PRINT "          BOEING 737/200     "
    LOCATE 23, 25: PRINT "TYPE " + CHR$(&H22) + "I" + CHR$(&H22) +
" FOR INFORMATION"
```

```
       LOCATE 2, 10:  PRINT "                         BOEING 737/200
INFORMATION"
       LOCATE 3, 10:  PRINT "                         JT8D-17
ENGINES"
       LOCATE 5, 1:   PRINT
"-----------------------------------------------------------------
--------------"
       LOCATE 7, 10:  PRINT "ALLOWABLE WEIGHT RANGES...........:
75,000 TO 120,000 POUNDS"
       LOCATE 9, 10:  PRINT "ALLOWABLE TAKEOFF FLAP SETTINGS...:
1, 2, 5, 15, 20, 25 DEGREES"
       LOCATE 11, 10: PRINT "ALLOWABLE LANDING FLAP SETTINGS...:
30, 40 DEGREES"
       LOCATE 13, 10: PRINT "TAKEOFF EPR AT SEA LEVEL, STD. DAY:
2.1  "
       LOCATE 15, 10: PRINT "REFERENCE WING AREA...............:
980 SQUARE FEET"
       LOCATE 17, 10: PRINT "REFERENCE TAKEOFF SPEED...........:
V2 + 10"
       LOCATE 19, 10: PRINT "REFERENCE LANDING SPEED...........:
1.3 Vs"
       LOCATE 23, 26: PRINT "Press Any Key to Continue..."
       DO: LOOP WHILE INKEY$ = ""
    END IF
    ANS$ = "2"
    CLS
    WHILE (ANS$ = "2")
      LOCATE 10, 30: PRINT "fly  ...... 1"
      LOCATE 12, 30: PRINT "plot ...... 2"
      LOCATE 14, 30: PRINT "exit ...... 3"
      LOCATE 18, 30: INPUT "Selection ..."; ANS$
      IF ANS$ = "2" THEN
                        CALL PLOT
                        COLOR 15, 1
                        CLS
      END IF
    WEND
    IF ANS$ = "3" THEN END
    CALL BEGIN      'GET DATA/INITIALIZE VARIABLES
    CALL THRUST     'INITIALIZE THRUST
    CALL TAKEOFF    'INITIALIZE TAKEOFF
    CALL COST       'SUBROUTINE COST
    CALL PRINTS     'SUBROUTINE PRINT
```

```
        CALL OPT       ' SUBROUTINE OPTIMIZE
        CALL LIMIT     ' SUBROUTINE ALPHA RATE
        CALL EULER     ' SUBROUTINE INTEGRATE
        CALL ATMOS     ' SUBROUTINE ATMOSPHERE
        CALL PRINTS    ' SUBROUTINE PRINT
        IF ALT < 0 THEN EXIT FOR

    NEXT ICL%

    PRINT "                                    RUN IS COMPLETE"
    PRINT "                                 TYPE " + CHR$(&H22) + "D" +
CHR$(&H22) + " FOR RUN DATA"
    a$ = ""

    DO WHILE a$ = ""   'Wait for key to be pressed
      a$ = INKEY$
    LOOP
    VIEW PRINT: COLOR 15, 4: CLS
    IF a$ = "D" OR a$ = "d" THEN
       a$ = ""

       LOCATE 2, 30: PRINT "DATA FROM CURRENT RUN"
       LOCATE 4, 1: PRINT
"------------------------------------------------------------------
--------------"
       LOCATE 6, 18: PRINT "GROSS WEIGHT:                    "; WG;
" POUNDS"
       LOCATE 7, 18: PRINT "ISA DEVIATION:                   ";
ISA; " DEG C"
       LOCATE 8, 18: PRINT "FLAP POSITION:                   ";
FLPS%; " DEGREES"
       LOCATE 9, 18: PRINT "GEAR POSITION:                   ";
GEAR$
       LOCATE 11, 18: PRINT "CONTROL LAW:                    ";
LAW%
       LOCATE 12, 18: PRINT "GAMMA REFERENCE:                ";
GAMREF
       LOCATE 13, 18: PRINT "PITCH LIMITING:                 ";
PL$
       IF PL$ = "YES" THEN LOCATE 13, 20: PRINT "MAXIMUM PITCH:
           "; HP * 57.3; " DEGREES": LOCATE 13, 20: PRINT
"MINIMUM PITCH:                 "; LP * 57.3; " DEGREES"
       LOCATE 15, 18: PRINT "TIME OF RUN:                    ";
```

```
          LOCATE 19, 18: PRINT "HORIZ. SHEAR DURATION:         ";
TDX; " SECONDS"
          LOCATE 20, 18: PRINT "VERT.  WIND  MAGNITUDE:        ";
WZ0 * 1.689; " FT/SECOND"
          LOCATE 21, 18: PRINT "VERT.  WIND  DURATION:         ";
TDZ; " SECONDS"
          LOCATE 22, 1: PRINT
"------------------------------------------------------------------
--------------"
       END IF
       IF LEN(OUTFILE$) = 0 THEN OUTFILE$ = "NONE"
       LOCATE 23, 18: PRINT "OUTPUT FILE:                    ";
OUTFILE$
       LOCATE 24, 26: PRINT "Press Any Key to Continue..."

       DO: LOOP WHILE INKEY$ = ""         'Wait for key to be
pressed

    END IF

    GOTO START
    END

SUB ATMOS STATIC

     '*************************************************
     '          SUBROUTINE ATMOSPHERE                  *
     '*************************************************

     STATIC THETA

     L% = ALT > 36089!
     FISA = 1.8 * ISA

     IF ALT > 36089 THEN
                          TMP = .7519 * T0
                          DELTA = .2234 * EXP((36089! - ALT) /
20806)
                      ELSE
                          TMP = T0 - .0035662 * ALT
                          DELTA = (TMP / T0) ^ 5.256
     END IF
```

```
     VC = A0 * SQR(5 * (((1 + MACH * MACH / 5) ^ 3.5 - 1) * DELTA
+ 1) ^ .28571 - 5)
     TAX = (TMP + FISA) * (1 + .2 * MACH * MACH)    'Deg. R
     TAT = 5 * (TAX - 459.7 - 32) / 9               'Deg. C

     IF INKEY$ <> "" THEN PRINT : INPUT "Press ENTER to
continue..."; XXX

END SUB

SUB BEGIN STATIC
    CLS : VIEW PRINT

    '<---------------- DATA_INPUT ---------------->

    PRINT
    INPUT "OUTPUT FILE (DEFAULT IS NO FILE) "; OUTFILE$

    IF OUTFILE$ = "" THEN
                        NOSAVE = 1
                    ELSE
                        NOSAVE = 0
    END IF

    ' CONSTANTS USED IN CALCULATIONS:

    A0 = 661.478599#        'Speed of sound at sea level in knots
    G = 19.07583            'Gravitational constant in knots/sec
    T0 = 518.67             'Standard temperature at SL in deg
Rankine
    DT = .25                'Simulation time step in seconds

    ' ----------------- INITIALIZATION OF VARIABLES
------------------

    GMIN = 0
    VDOT = 0
    ALT1 = 0
    INPUT "TAKEOFF OR APPROACH  (T/A)   (Default is T)...."; ANS$

    IF ANS$ = "a" OR ANS$ = "A" THEN
                                INPUT "ENTER ALTITUDE IN FEET
```

```
------------------------

    ASS = 16.5                                  'Stick Shaker alpha in
degrees
    ASS = ASS / 57.3                            ' "      "      "     "
radians

    '--------------------- GROSS WEIGHT ENTRY
----------------------

    PRINT : INPUT "ENTER GROSS WEIGHT IN POUNDS (Default is
110000) "; WG
    IF WG = 0 THEN WG = 110000!        ' DEFAULT SETTING

    FL% = 0

    WHILE (NOT FL%)

       INPUT "ENTER FLAPS SETTING          (Default is  0).....";
FLPS%

       SELECT CASE FLPS%
       CASE 0, 1, 2, 5, 15, 20, 25, 30, 40
          FL% = -1
       CASE ELSE
          FL% = 0
          PRINT "Invalid flaps setting"
          PRINT "Only 0, 1, 2, 5, 15, 20, 25, 30 & 40 are
supported"
          PRINT
       END SELECT

    WEND


    IF FLPS% < 15 THEN GEAR% = 1
    IF FLPS% = 15 THEN INPUT "GEAR UP OR DOWN   (1/0)
(Default is Down)..."; GEAR%
    IF GEAR% = 1 THEN
                     GEAR$ = " UP"
                 ELSE
                     GEAR$ = " DOWN"
```

```
PRINT "                    CONTROL LAW SELECTION:"
PRINT
PRINT "               Speed = 1.1* V_stall               = 1"
PRINT "               Alpha = Stick Shaker Alpha         = 2"
PRINT "               Horizontal Acceleration = 0        = 3"
PRINT "               15_Degree Pitch                    = 4"
PRINT "               Theoretical HONEYWELL/SPERRY       = 5"
PRINT "               User Defined                       = 6"
PRINT
INPUT "               SELECT CONTROL LAW ........... "; LAW%

 IF LAW% = 0 THEN LAW% = 5

 PRINT : PRINT

 '--------------------- GAMMA REFERENCE INPUT
-----------------

 IF LAW% > 4 THEN
    INPUT "ENTER GAMMA REFERENCE IN DEGREES (Default is
0)........"; GMR
    PRINT
    GAMREF = GMR
    GMR = GMR / 57.3: GMIN = GMR
 END IF

 '----------------- PITCH LIMITING SELECTION
--------------------

 INPUT "PITCH LIMITING DESIRED (Default is
NO)................."; PL$

 IF PL$ = "Y" OR PL$ = "y" THEN

    PL$ = "YES"
    INPUT "     MAXIMUM PITCH ALLOWED IN DEGREES "; HP
    INPUT "     MINIMUM PITCH ALLOWED IN DEGREES "; LP
    HP = HP / 57.3: LP = LP / 57.3: PL% = 1

 ELSE
```

```
     '------------------------- TIME FOR RUN
-------------------------------
     PRINT
     INPUT "ENTER TIME OF RUN IN SECONDS (Default is
45)..........."; TTT
     TTT = TTT / DT
     IF TTT = 0 THEN TTT = 45 / DT           ' DEFAULT SETTING
     '------------------------- WINDSHEAR SET UP
----------------------------
     INPUT "DALLAS/FW Wind Model.....(Default is constant
Shear)..."; ANS$

     IF ANS$ = "Y" OR ANS$ = "y" THEN
        DFW% = 1
                                        ELSE
        DFW% = 0
        PRINT
        INPUT "MAGNITUDE OF HORZ. WIND IN KNOTS..(Head wind <
0)..... "; WX0
        INPUT "MAGNITUDE OF HORZ SHEAR IN KT/SEC.(Dec. Perf.>
0)..... "; WXDT0
        INPUT "DURATION  OF HORZ SHEAR IN SEC....(Default is
0)......."; TDX
        INPUT "TIME FOR SHEAR TO START IN SEC....(Default is
0)......."; TSH
        PRINT

        INPUT "MAGNITUDE OF VERT. WIND IN FT/SEC.(Down Draft <
0).... "; WZ0
        WZ0 = WZ0 / 1.689       'Convert to knots
        INPUT "DURATION  OF VERT. WIND IN SEC....(Default is 0)...
  "; TDZ
        INPUT "TIME FOR SHEAR TO START IN SEC....(Default is
0)......."; TSV
        PRINT
     END IF

     '------------------- OTHER SET UPS
------------------------------------
     VT = VT0
     WX = WX0

     CALL ATMOS    ' SUBROUTINE ATMOSPHERE
```

```
    '***********************************
    '      SUBROUTINE INIT_OUTPUT FILE   *
    '***********************************
    IF NOSAVE THEN  ' CREATE OUTPUT FILE
    ELSE
       OPEN "O", 2, OUTFILE$
       FMT$ = " ###.##  #####  #####  ####  ####  ##  ###.##
###.##  ###.##"
       FMT$ = FMT$ + " ###.##  ###.#  ###.#  ##.## "
    END IF

END SUB

SUB COST STATIC

    '*****************************************************
    '                     SUBROUTINE COST                 *
    '*****************************************************

    CALL DRAGS                    ' SUBROUTINE DRAG & LIFT

    CALL RATES                    ' SUBROUTINE RATES


    IF LC% = 0 THEN               'Constant gamma segment

                FCT = (GM + GDOT * DT - GM0) ^ 2
                GREFF = 57.3 * GM0

            ELSE                  'All guidance laws


        SELECT CASE LAW%

            CASE 1  '--------------- 1.1*Vstall
--------------------

            CST = (VT + VDOT * DT - 1.1 * 135) ^ 2

            CASE 2  '--------------- Alpha = Ass
--------------------
```

```
---------------------

                  CST = (GM + 3 * GDOT * DT + ALPHA - 15 / 57.3) ^ 2

                  CASE 5  '---------- User Defined
------------------------

                          PRINT "Not defined"
                          STOP

                  CASE 6  '----------- User Supplied
-----------------------

                    'User must supply a subroutine called GUIDE
                    'which must  reside in the WNDSHR.QLB Library
                    'GUIDE can have a list of arguments
                    'As an example

                    'ALF = 57.3*ALPHA
                    'PTH = 57.3 * (ALPHA + GM)

                    ' units :    ft   fpm  kt  deg  deg  g's g's  *


                    'CALL GUIDE(ALT, HDOT, VC, ALF, PTH, AU, AZ,
CST)

           END SELECT
     END IF

     '     CST is the Cost Function to be minimized

END SUB

     SUB DRAGS STATIC
      '*****************************************************
      '     SUBROUTINE DRAG   FOR B737/200                  *
      '*****************************************************
      X = 57.3 * ALPHA + 1
```

```
CASE 1
     CF3 = -1.164058E-04
     CF2 = 2.48561E-03
     CF1 = .0905781
     CF0 = .062114

CASE 2
     CF0 = .101198
     CF1 = .110993
     CF2 = -.0015162
     CF3 = 1.8931E-04
     CF4 = -7.1427E-06
     CF5 = -4.2776E-09

CASE 5
     CF0 = .192638
     CF1 = .123509
     CF2 = -.0051477
     CF3 = 6.4968E-04
     CF4 = -3.0891E-05
     CF5 = 4.1291E-07

CASE 10
     CF0 = .249855
     CF1 = .114005
     CF2 = 7.1207E-04
     CF3 = -9.9541E-05
     CF4 = 7.0431E-06
     CF5 = -2.3773E-07

CASE 15
     CF0 = .40149
     CF1 = .118723
     CF2 = -6.4877E-04
     CF3 = 6.6281E-05
     CF4 = -1.6113E-07
     CF5 = -1.4278E-07
```

```
                CASE 30
                     IF X < 4 THEN
                                    CF1 = .12
                                    CF0 = .72
                          ELSE
                                    CF3 = -1.651192E-04
                                    CF2 = 4.16461E-03
                                    CF1 = 8.337061E-02
                                    CF0 = .8350316
                     END IF
                CASE 40
                     IF X < 4 THEN
                                    CF1 = .12
                                    CF0 = 1.08
                          ELSE
                                    CF3 = -1.689903E-04
                                    CF2 = 3.733285E-03
                                    CF1 = 8.483822E-02
                                    CF0 = 1.201596
                     END IF

                CASE ELSE
                     PRINT "Flaps "; FLPS%; " not available..."
                     END

          END SELECT              'For CL computation

          CL = ((((CF5 * X + CF4) * X + CF3) * X + CF2) * X + CF1) * X
+ CF0


          SELECT CASE FLPS%       'Low Speed Drag Polars

                CASE 0
                     D0 = .013285: D1 = .052868: D2 = -.07182: D3 =
.071561
                CASE 1
                     D0 = .026143: D1 = .022358: D2 = -.00083: D3 =
.016338
                CASE 2
                     D0 = .070346: D1 = -.0852: D2 = .097453: D3 =
-.01207
```

```
                    IF GEAR% = 0 THEN
                                        D0 = .034954: D1 = .098892: D2
= -.04187: D3 = .020496
                                   ELSE
                                        D0 = -.02822: D1 = .174631: D2
= -.0874: D3 = .029566
                    END IF
               CASE 25
                    D0 = -.10416: D1 = .327506: D2 = -.17059: D3 =
.043313
               CASE 30
                    D0 = .124697: D1 = -.03348: D2 = .055295: D3 =
-.00311
               CASE 40
                    D0 = .124925: D1 = .052537: D2 = .006912: D3 =
.0058
               CASE ELSE
                    PRINT "Flaps "; FLPS%; " not available..."
                    END
       END SELECT
       CD = ((D3 * CL + D2) * CL + D1) * CL + D0
       Q = 1451770 * MACH * MACH * DELTA       'B737/200
       LIFT = Q * CL
       DRAG = Q * CD
      END SUB

SUB EULER STATIC

     '******************************************************
     '    SUBROUTINE EULER'S PREDICTOR/CORRECTOR            *
     '          (INTEGRATION SUBROUTINE)
     '******************************************************
     DTH = DT / 3600: DTM = DT / 60: SEC = SEC + DT: VTP = VT

     CALL RATES    ' SUBROUTINE RATES  <<PREDICTOR>>

     ALT1 = ALT: HDOT1 = HDOT: ALT = ALT + HDOT * DTM
     GM1 = GM: GDOT1 = GDOT: GM = GM + GDOT * DT
     DST1 = DST: XDOT1 = XDOT: DST = DST + XDOT * DTH
     VT1 = VT: VDOT1 = VDOT: VT = VT + VDOT * DT

     CALL RATES    ' SUBROUTINE RATES  <<CORRECTOR>>
```

```
'*****************************************************************
   '
  *                SUBROUTINE ALPHA DOT AND PITCH LIMIT

'*****************************************************************

     ALPHA = OLDALF + .25 * (ACMD - OLDALF)  'Pitch dynamics

     CALL DRAGS   ' SUBROUTINE DRAG (REQ'D FOR RATE SUB CALL)

     IF PLMFLG% = 0 THEN EXIT SUB

     OLDGM = GM
     PLIM% = 0

    DO WHILE (PLIM% = 0)

     CALL RATES   ' SUBROUTINE RATES

     X = ALPHA + OLDGM + GDOT * DT
     IF X > HP THEN ALPHA = .9 * ALPHA
     IF X < LP THEN ALPHA = 1.1 * ALPHA
     IF ALPHA > ALFLIM THEN
                           ALPHA = ALFLIM
                           PLIM% = 1
     END IF
    LOOP

END SUB

    SUB MCRBRST STATIC

    IF MU1 = 0 THEN
                  MU1 = -37141!
                  AV = 5500: H1 = 2500: G3 = 3: J1 = -700: J2 =
800: J3 = 6.5
                  MU2 = -20000
                  BV = 12000: H2 = 2000: N1 = 200: N2 = 2500: N3
= 4
```

```
                    END IF
     END IF

     X = 6078 * DST: Y = ALT: A1 = AV: A2 = BV

     NX1 = Y - H1: DENX1 = (Y - H1) ^ 2 + (X - A1) ^ 2
     NY1 = X + J2 - A1: DENY1 = (Y + J1 - H1) ^ 2 + (X + J2 - A1) ^
2
     NX2 = Y - H2: DENX2 = (Y - H2) ^ 2 + (X - A2) ^ 2
     NY2 = X + N2 - A2: DENY2 = (Y + N1 - H2) ^ 2 + (X + N2 - A2) ^
2
     NX3 = Y + H1: DENX3 = (Y + H1) ^ 2 + (X - A1) ^ 2
     NY3 = X + J2 - A1: DENY3 = (Y + J1 + H1) ^ 2 + (X + J2 - A1) ^
2
     NX4 = Y + H2: DENX4 = (Y + H2) ^ 2 + (X - A2) ^ 2
     NY4 = X + N2 - A2: DENY4 = (Y + N1 + H2) ^ 2 + (X + N2 - A2) ^
2

     XX = MU1 * (-NX1 / DENX1 + NX3 / DENX3) + MU2 * (NX2 / DENX2 -
NX4 / DENX4)
     WX = WX + .65 * (XX - WX) + 2 * G3

     IF DST = 0 THEN WXP = WX

     ZZ = MU1 * (NY1 / DENY1 - NY3 / DENY3) * J3 + MU2 * (-NY2 /
DENY2 + NY4 / DENY4) * N3
     WZ = WZ + .65 * (ZZ - WZ)

     IF DST = 0 THEN WZP = WZ

     WX5 = WX4: WX4 = WX3: WX3 = WX2: WX2 = WX1: WX1 = WX
     WZ5 = WZ4: WZ4 = WZ3: WZ3 = WZ2: WZ2 = WZ1: WZ1 = WZ

     IF WCNT% < 4 THEN WXDT = (WX - WXP) / DT: WXP = WX
     IF WCNT% < 4 THEN WZDT = (WZ - WZP) / DT: WZP = WZ
     IF WCNT% > 3 THEN WXDT = (26 * WX5 - 27 * WX4 - 40 * WX3 - 13
* WX2 + 54 * WX1) / (70 * DT)
     IF WCNT% > 3 THEN WZDT = (26 * WZ5 - 27 * WZ4 - 40 * WZ3 - 13
* WZ2 + 54 * WZ1) / (70 * DT)
```

```
SUB MIN (DM, M2, C1, C2, C3, M) STATIC

    '*********************************************
    'SUBROUTINE MIN_CST BY LEAST SQUARES PARABOLA   *
    '*********************************************
    ALPHA = M2 + DM    'INCREMENT ALPHA

    CALL COST                        'SUBROUTINE COST

    IF DM < 0 THEN
       C4 = CST
    ELSE
       SWAP C1, C3
       C5 = CST
    END IF

    ALPHA = M2 - DM    'DECREMENT ALPHA

    CALL COST                        'SUBROUTINE COST

    IF DM < 0 THEN
       C5 = CST
    ELSE
       C4 = CST
    END IF

    M = ABS(DM) * (14 * C1 + 7 * C4 - 7 * C5 - 14 * C3) / (20 *
C1 - 10 * C4 - 20 * C2 - 10 * C5 + 20 * C3)
END SUB

SUB OPT STATIC

'**************************************************************
    'SUBROUTINE OPTALF - DETERMINES THE ALPHA REQD FOR CMD GAMMA
*

'**************************************************************

    OLDALF = ALPHA: GM1 = GM
    CALL ATMOS                  ' SUBROUTINE ATMOSPHERE

    CALL RATES                  ' SUBROUTINE RATES
```

```
      WHILE (OPTFLG% = 0)

      CALL COST                   ' SUBROUTINE COST

      C3 = C2: C2 = C1: C1 = CST
      M3 = M2: M2 = M1: M1 = ALPHA

      LGC% = C1 > C2 AND C3 = 1E+20

      IF LGC% THEN
                  DM = -DM  ' Reverse search direction
                  C1 = C2: C2 = CST: M1 = M2: M2 = ALPHA
                  ALPHA = ALPHA + 2 * DM
              ELSE
                  IF C1 < C2 THEN
                                 L% = ABS(OLDALF - ALPHA) / DT >
ALFRTE OR ALPHA > ALFLIM OR ALPHA < -.08
                                 IF L% THEN OPTFLG% = 1
                                 ALPHA = ALPHA + DM
                             ELSE
                                 DM = DM / 2
                                 CALL MIN(DM, M2, C1, C2, C3,
M)'Fit parabola & find minimum
                                 ALPHA = M2 + M 'This is the
optimum alpha
                                 OPTFLG% = 1    'Set flag to
terminate
                  END IF
      END IF
      WEND

      ALFLIM = ASS                  'SET ALPHA LIMIT TO ALPHA STICK
SHAKER

      SELECT CASE LAW%

      CASE 4
         ALFLIM = ASS - .035 'LIMIT TO SS MINUS 2 DEG
      CASE 5, 6
         ALFLIM = ASS - KF2
      CASE ELSE
```

```
END SUB

SUB PLOT

'****************************************************************
******
    '*                                PLOT  ROUTINE
         *   *

'****************************************************************
******

    REM $DYNAMIC

    '              TWO DIMENSIONAL PLOTTER

    DEFINT I-L, N

    DIM F$(3)                  ' file name array
    DIM DTA(3, 1000, 15)       ' data array
    DIM TY$(14)                ' title array (dependant variable)


    TITLE$ = "HONEYWELL WINDSHEAR SIMULATION"  ' main title
    TX$ = "Time (s)"                           '  X   title


    TY$(1) = "Altitude ft  "
    TY$(2) = "Alt Rate fpm "
    TY$(3) = "T A S    kts "
    TY$(4) = "Alpha    deg "
    TY$(5) = "Gamma    deg "
    TY$(6) = "Pitch    deg "
    TY$(7) = "G_ref    deg "
    TY$(8) = "Hz Shear kps "
    TY$(9) = "Vt Wind  fps "
    TY$(10) = "Vt rate kps "
    TY$(11) = "W/S Flag     "

    NV = 12
    CLS
```

```
        IF F$(NC) = "" THEN EXIT FOR    ' data
     NEXT NC

     NC = NC - 1                        ' number of curves to plot

     LOCATE 20, 15: PRINT "Reading from disk ..."

     FOR I = 1 TO NC

        CLOSE

        OPEN "I", #1, F$(I)    ' open file for input

        NP = 0

        DO
           NP = NP + 1                    ' number of points

           FOR J = 1 TO NV

              INPUT #1, DTA(I, NP, J)     ' read data

           NEXT J

        LOOP UNTIL EOF(1)

        CLOSE
     NEXT I


     DO ' display all selected parameters


        DO ' prompt user until a valid parameter is selected
100        CLS

           LOCATE 3, 20: PRINT "Select the parameter you wish to
plot."

           FOR I = 1 TO NV - 1
```

```
      IF PARAM% = 0 THEN
         CLS
         EXIT SUB            ' return to calling program
      END IF

   LOOP UNTIL 1 <= PARAM% AND PARAM% <= 14   'end of select
loop

   PARAM% = PARAM% + 1



   DX = 5          ' X axis grid increment

   GOSUB 400     ' find maximum X and Y values

   IF PLTFLG% = 1 THEN
                     PRINT "No information  to plot..."
                     PRINT "Press any key to continue.."
                     DO: LOOP WHILE INKEY$ = ""
                     GOTO 100
   END IF

   GOSUB 600     ' grid and titles

   FOR I = 1 TO NC
     GOSUB 1110     ' plot graph
   NEXT I


   DO
   LOOP WHILE INKEY$ = ""

   CLS : SCREEN 0

LOOP
```

```
MAXX = DTA(1, 1, 1)
MAXY = DTA(1, 1, PARAM%)
MINY = DTA(1, 1, PARAM%)

FOR I = 1 TO NC
  FOR J = 1 TO NP
    IF DTA(I, J, 1) > MAXX THEN MAXX = DTA(I, J, 1)
    IF DTA(I, J, PARAM%) > MAXY THEN MAXY = DTA(I, J, PARAM%)

    IF DTA(I, J, PARAM%) < MINY THEN MINY = DTA(I, J, PARAM%)

  NEXT J
NEXT I

PLTFLG% = 0
DY = (MAXY - MINY) / 15
IF DY = 0 THEN
              PLTFLG% = 1
              DY = 5
END IF
MAG = 10 ^ (INT(LOG(DY) / LOG(10))): DY = DY / MAG

IF DY <= 5 THEN
   DY = 5
ELSE
   DY = 10
END IF

DY = DY * MAG


IF INT(MAXX / DX) <> MAXX / DX THEN MAXX = INT(MAXX / DX + 1)
* DX
IF INT(MAXY / DY) <> MAXY / DY THEN MAXY = INT(MAXY / DY + 1)
* DY
IF INT(MINY / DY) <> MINY / DY THEN MINY = INT(MINY / DY) * DY


NUMX = MAXX / DX
NUMY = (MAXY - MINY) / DY
RETURN
```

```
*********
'
CLS
SCREEN 2                        ' 640*200 monochrome graphics
KEY OFF
'
FOR J = 0 TO NUMX
  Z = J * 580 / NUMX + 59
  LINE (Z, 10)-(Z, 170)             ' vertical grid line
  Z = J * 71 / NUMX + 7

  a = DX * J

  IF a <> 0 THEN                            ' adjustment for
     D = INT(LOG(a) / LOG(10)) + 1          ' large numbers
     IF D > 1 THEN Z = Z - D + 1
  END IF

  LOCATE 23, Z
  PRINT a;
NEXT J

FOR J = 0 TO NUMY
Z = J * 160 / NUMY + 10
LINE (60, Z)-(640, Z)               ' horizontal grid line
Z = 22 - J * 20 / NUMY

LOCATE Z, 2

Z = DY * J + MINY

AZ = ABS(Z)

IF INT(Z) = Z THEN
                               G$ = "######"
ELSEIF AZ < .1 THEN
                               G$ = "#.####"
ELSEIF AZ >= .1 AND AZ < 1 THEN
                               G$ = "##.###"
ELSEIF AZ >= 1 AND AZ < 10 THEN
                               G$ = "###.##"
ELSEIF AZ >= 10 AND AZ < 100 THEN
                               G$ = "####.#"
```

```
Z = (80 - LEN(TITLE$)) / 2 + 2
LOCATE 1, Z: PRINT TITLE$ ' print main title

LOCATE 24, 36: PRINT TX$;  ' X axis title

LOCATE 8, 1                                  ' Y

FOR J = 1 TO LEN(TY$(PARAM% - 1))            ' axis
   PRINT MID$(TY$(PARAM% - 1), J, 1)         ' title
NEXT J

LOCATE 25, 10: PRINT "1";                   ' curve
LINE (90, 195)-(130, 195)
LOCATE 25, 20: PRINT "2";                   ' labels
 FOR J = 0 TO 40 STEP 8
   XX = 170 + J
   PSET (XX, 195)
   CIRCLE (XX + 80, 195), 2
 NEXT J
 LOCATE 25, 30: PRINT "3";
 RETURN

'*****************************************************************
*********
    '*                          PLOTTING ROUTINE
          *

'*****************************************************************
*********
    '
1110 FOR J = 1 TO NP
      XX = 580 * DTA(I, J, 1) / MAXX + 60' calculate pixel X
postiion
      YY = 170 - 160 * (DTA(I, J, PARAM%) - MINY) / (MAXY - MINY)


      IF J = 1 OR J = NP THEN GOTO 1170
      IF I = 1 THEN LINE (XXOLD, YYOLD)-(XX, YY) ' line
1170  XXOLD = XX

      YYOLD = YY
```

```
REM $STATIC
DEFSNG I-L, N
     SUB PRINTS

     '**********************************************
     '       SUBROUTINE PRINT TO SCREEN AND FILE    *
     '**********************************************
     ACMDG = 57.3 * ACMD
     ALF = 57.3 * ALPHA
     GAM = 57.3 * GM
     PITCH = ALF + GAM
     WZX = 1.689 * WZ
     IF NOSAVE = 0 THEN PRINT #2, SEC, ALT, HDOT, VT, ALF, GAM,
PITCH, GREFF, WXDT, WZX, VDOT, WSALERT%
     FMT1$ = "###.##  ####  #####  ###  ###.#  ###.#  ###.#  ##.#
###.# ###.# ###.#   #"
     PRINT USING FMT1$; SEC, ALT, HDOT, VT, ALF, GAM, PITCH,
GREFF, WXDT, WZX, VDOT, WSALERT%

     END SUB

SUB RATES STATIC

     '*************************************************
     '                SUBROUTINE RATES                 *
     '*************************************************
     SNGM = SIN(GM): CSGM = COS(GM): SNAL = SIN(ALPHA): CSAL =
COS(ALPHA)
     VDOT = G * ((THRST * CSAL - DRAG) / WG - SNGM) - WXDT * CSGM
- WZDT * SNGM
     GDOT = G * ((LIFT + THRST * SNAL) / WG - CSGM) + WXDT * SNGM
- WZDT * CSGM
     GDOT = GDOT / VT
     HDOT = 101.28 * (VT * SNGM + WZ)
     XDOT = VT * CSGM + WX

     AWX = VDOT + WXDT * CSGM + WZDT * SNGM       'Inertial Acc.
along Wind_x axis
     AWZ = VT * GDOT - WXDT * SNGM + WZDT * CSGM  '    "     "
 "   Wind_z axis
```

```
     KF1 = 1
     GHAT = GMIN * (1 + WX / VT)
     IF WZ > -30 AND WZ < -20 THEN KF1 = 1 + .025 * (WZ + 20)
     IF WZ <= -30 THEN KF1 = .75
     DGAM = 57.3 * (20 * GDOT - (GHAT - GRND + (1 - KF1) * WZ /
152 + 20 * GDOT))

     IF DGAM < 0 THEN
        KF2 = (2 + .4 * DGAM)
     ELSE
        KF2 = 2
     END IF

     IF KF2 < 0 THEN KF2 = 0
     KF2 = KF2 / 57.3

END SUB

SUB TAKEOFF STATIC

     '****************************************************
     '              SUBROUTINE INITIALIZE TAKEOFF        *
     '****************************************************
     IF APPFLG% = 0 THEN
                         ALPHA = .12
                         WHILE (LIFT <= WG)
                           CALL DRAGS
                           ALPHA = ALPHA + .01
                         WEND
                         GM = (THRST - DRAG) / WG  'COMPUTE
POTENTIAL GAMMA
                     ELSE
                         GM = -3 / 57.3
                         ALPHA = 2 / 57.3
                         CALL DRAGS
                         TFCT = 1
                         CALL THRUST
                         T = DRAG - .052 * WG
                         IF T < 0 THEN T = .2 * THRST
                         TFCT = T / THRST
                         THRST = T
```

```
'*********************************************************
'                 SUBROUTINE EPR/THRUST                  *
'*********************************************************
'        TAKE-OFF THRUST FOR JT8D-17 ENGINES
     VE = 1.668 * VT

     R00 = 14688.74: R01 = -.65187546#: R02 = 6.7371E-05
     R10 = -13.9295: R11 = .000751143#: R12 = -1.5405E-07
     R20 = .014643: R21 = 5.3444E-07: R22 = -4.8907E-10

     AA0 = (R02 * ALT + R01) * ALT + R00
     AA1 = (R12 * ALT + R11) * ALT + R10
     AA2 = (R22 * ALT + R21) * ALT + R20

     THRST = 2 * ((AA2 * VT + AA1) * VT + AA0)    'Temp. = 100 F

     IF APPFLG% = 1 THEN
                  IF LC% = 1 AND TFCT < 1 THEN
                                             GM0 = .136
                                             TSPL = 5.5
'Engine Spool Up Time
                                             TFCT = TFCT +
DT / TSPL
                  END IF
                  IF TFCT > 1 THEN TFCT = 1
               ELSE
                  TFCT = 1
     END IF
     THRST = TFCT * THRST
''     THRST = 2 * (((2.64159E-05 * VT + 5.110896E-03) * VT -
12.56476) * VT + 15550)
END SUB

SUB VSHAKER STATIC

     '------------------- COMPUTATION OF Vss AND V2
---------------
     V2 = 145
     VT0 = V2 + 10'        SETS INITAL SPEED EQUAL TO V2+10

     SELECT CASE FLPS%
```

```
   VTO = 63.11225 + .222468 * WG / 1000   ' APPROACH
CASE 42                                   ' FLAP
   VTO = 62.67386 + .21744 * WG / 1000    ' SETTINGS

CASE ELSE

END SELECT

END SUB

SUB WINDS STATIC

'*******************************************************
'                SUBROUTINE WINDS                      *
'*******************************************************
'
IF TDX > 0 THEN
                  T1 = 4
                  T2 = TSH
                  T3 = T1 + T2
                  T4 = -4
                  T5 = T3 + TDX
                  T6 = T5 - T4

                  B1 = 3 * WXDT0 / T1 ^ 2
                  A1 = -2 * B1 / (3 * T1)
                  B2 = 3 * WXDT0 / T4 ^ 2
                  A2 = -2 * B2 / (3 * T4)

                  IF SEC > T2 AND SEC <= T3 THEN
                                                X = SEC - T2

                                                WXDT = (A1 *
X + B1) * X * X
                  END IF

                  IF SEC > T5 AND SEC <= T6 THEN
                                                X = SEC - T6

                                                WXDT = (A2 *
X + B2) * X * X
```

```
T1 = 4
T2 = TSV
T3 = T1 + T2
T4 = -4
T5 = T3 + TDZ
T6 = T5 - T4

B1 = 3 * WZ0 / T1 ^ 2
A1 = -2 * B1 / (3 * T1)
B2 = 3 * WZ0 / T4 ^ 2
A2 = -2 * B2 / (3 * T4)

IF SEC > T2 AND SEC <= T3 THEN
        X = SEC - T2
        WZ = (A1 * X +
B1) * X * X

        WZC = WZ
END IF

IF SEC > T5 AND SEC <= T6 THEN
        X = SEC - T6
        WZ = (A2 * X +
B2) * X * X

        WZC = WZ
END IF

KALT = (-.0000011 * ALT + .00212) * ALT -
.0251

IF KALT < 0 OR ALT <= 0 THEN KALT = 0
KALT = 1
WZ = KALT * WZC

IF SEC > T6 THEN WZ = 0

WZDT = (WZ - WZ1) / DT
WZ1 = WZ
    END IF

    IF DFW% = 1 THEN CALL MCRBRST        'Dallas Model

END SUB
^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z
^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z
^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z
```